Reliability and Effect of Sodium Bicarbonate: Buffering and 2000-m Rowing Performance

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Purpose: The aim of this study was to determine the effect and reliability of acute and chronic sodium bicarbonate ingestion for 2000-m rowing ergometer performance (watts) and blood bicarbonate concentration \([\text{HCO}_3^-]\).

Methods: In a crossover study, 7 well-trained rowers performed paired 2000-m rowing ergometer trials under 3 double-blinded conditions: (1) 0.3 grams per kilogram of body mass (g/kg BM) acute bicarbonate; (2) 0.5 g/kg BM daily chronic bicarbonate for 3 d; and (3) calcium carbonate placebo, in semi-counterbalanced order. For 2000-m performance and \([\text{HCO}_3^-]\), we examined differences in effects between conditions via pairwise comparisons, with differences interpreted in relation to the likelihood of exceeding smallest worthwhile change thresholds for each variable. We also calculated the within-subject variation (percent typical error).

Results: There were only trivial differences in 2000-m performance between placebo (277 ± 60 W), acute bicarbonate (280 ± 65 W) and chronic bicarbonate (282 ± 65 W); however, \([\text{HCO}_3^-]\) was substantially greater after acute bicarbonate, than with chronic loading and placebo. Typical error for 2000-m mean power was 2.1% (90% confidence interval 1.4 to 4.0%) for acute bicarbonate, 3.6% (2.5 to 7.0%) for chronic bicarbonate, and 1.6% (1.1 to 3.0%) for placebo. Postsupplementation \([\text{HCO}_3^-]\) typical error was 7.3% (5.0 to 14.5%) for acute bicarbonate, 2.9% (2.0 to 5.7%) for chronic bicarbonate and 6.0% (1.4 to 11.9%) for placebo.

Conclusion: Performance in 2000-m rowing ergometer trials may not substantially improve after acute or chronic bicarbonate loading. However, performances will be reliable with both acute and chronic bicarbonate loading protocols.

Keywords: induced alkalosis, ergometer performance, rowing regatta, typical error, individual differences

The physiological effects of sodium bicarbonate ingestion and the subsequent performance implications in high-intensity exercise lasting 1–7 min have been investigated since the 1930s. Sodium bicarbonate ingestion induces alkalosis and manifests as increased blood bicarbonate concentration, \([\text{HCO}_3^-]\), with a standard dose of 0.3 grams per kilogram of body mass (g/kg BM) increasing resting \([\text{HCO}_3^-]\) by ~6 mmol/L. The majority of bicarbonate loading studies have focused on acute protocols, with the entire dose being consumed 1–3 h before the exercise test. More recently, “chronic” or longer duration bicarbonate supplementation strategies have been investigated in an attempt to ameliorate the gastrointestinal side effects often associated with acute loading. The “chronic” protocols, which involve 3–5 d of a daily bicarbonate intake of 0.5 g/kg BM split into 3–4 doses, can produce performance enhancements and elevations in \([\text{HCO}_3^-]\) similar to those achieved with acute loading.

The 2000-m rowing event, involving 5–8 min of high-intensity exercise resulting in high levels of lactic acidosis, has been identified as a potential target of strategies to enhance buffering capacity. Although several studies have investigated the effect of sodium bicarbonate supplementation on rowing performance, the protocols have been limited to effects of acute loading with single rowing ergometer efforts. Meanwhile, investigations of other dietary interventions on rowing performance have incorporated repeated ergometer trials over several days to better simulate the demands of multiday regatta racing.

We were interested to study the effects of repeated bicarbonate loading strategies on ergometer trials undertaken 48 h apart both because of its relevance to real-life and the physiological issue of repeating alkalinizing strategies. Furthermore, repeated trials present the opportunity to measure the reliability of measures such as performance (mean power, stroke rate), induced alkalosis \([\text{HCO}_3^-]\) and associated test measures; blood lactate concentration \([\text{La}^-]\); rating of perceived exertion (RPE); and gastrointestinal (GI) symptoms. Specifically, the typical error can be calculated via changes between repeated trials, and quantifies the expected variation from one assessment to the next. Therefore, observed changes in athletes’ performance on different occasions can be
interpreted as real changes or as an artifact of the error or uncertainty associated with that measure.12 Or in other words, typical error allows calculation of the “noise” in a measure, so that one can determine both the “signal” and the “noise” simultaneously. Typical error, when calculated for both experimental and control groups, has further practical application—quantifying the variation from the mean treatment response between individuals, which can aid sport scientists in interpreting true changes when monitoring individual athletes.12

Accordingly, the purpose of this investigation was to determine the effect and reliability of both acute and chronic sodium bicarbonate supplementation on (a) induced alkalosis [HCO3–] and subsequent repeated 2000-m rowing ergometer performance and (b) associated test measures ([La−], RPE, GI symptoms).

Methods

Subjects

Seven well-trained rowers participated in this study (4 males and 3 females; mean ± SD age 25.0 ± 11.7 y; body mass 79.7 ± 10.8 kg; height 179.3 ± 8.5 cm; sum of 7 skinfolds 76.3 ± 21.7 mm). All were experienced with performing 2000-m rowing ergometer tests with personal best times of 6:33.6 min:s ± 17.6 s for males and 7:27 min:s ± 28.8 s for females. Prior written consent was obtained from each subject, and the protocol was approved by the Ethics Committee of the Australian Institute of Sport.

Design

In a crossover design, subjects completed performance tests under three double-blinded conditions (chronic bicarbonate, acute bicarbonate, and placebo) in semi-counterbalanced order. Testing for each condition comprised two trials, separated by 48 h, to simulate the repeated performance efforts required when competing in a major regatta. Therefore, each subject completed a total of 6 performance tests over an 18-d testing period (Figure 1).

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 h before the first 2000-m test. These dietary and training patterns were repeated before each subsequent test, and compliance with these protocols was checked on the morning of each trial before subjects were cleared to proceed with the study.

Supplement Ingestion

In the acute bicarbonate condition, subjects ingested 0.3 g/kg BM sodium bicarbonate capsules (Sodibic, Aspen Pharmacare, St. Leonards, Australia) 120 min before the first and second trials. In the chronic bicarbonate condition, subjects ingested 0.5 g/kg BM sodium bicarbonate daily for a period of 3 d. The sodium bicarbonate capsules were subdivided into 0.1 g/kg BM doses that subjects coingested with meals and snacks throughout each day. No sodium bicarbonate capsules were ingested acutely before the chronic bicarbonate supplementation trials. Therefore, for an 80-kg subject, a total of 40 capsules per day (subdivided into 5 × 8 capsule doses) would be ingested each day for 3 d.

The first chronic bicarbonate performance trial was performed after the first day of 0.5 g/kg BM bicarbonate ingestion, and the second trial after 3 d of 0.5 g/kg BM bicarbonate ingestion (Figure 1). Therefore, subjects completed the 2 chronic bicarbonate trials under nonidentical conditions. We specifically used this chronic bicarbonate supplementation strategy because it simulated a rowing regatta, in which races are often 48 h apart over a 5-d period and it would be impractical for athletes to ingest bicarbonate for a period longer than 3 d. From a reliability perspective, other researchers have demonstrated no substantial differences in induced alkalosis between the first and third days of chronic ingestion. Their research suggests that there would be minor differences in subjects’ blood-buffering capacity before their first and second chronic bicarbonate trials.

Figure 1 — Overview of the timing of ergometer tests and capsule ingestion. 2000-m ergometer trials in the three conditions were separated by 48 h. The first chronic bicarbonate trial was performed after 1 d of bicarbonate ingestion and the second trial after 3 d of loading.
Timing of capsule ingestion, pretest meal composition, and coingested fluids were standardized across all conditions to maintain subjects’ blinding to the experimental conditions. Therefore, in the placebo condition, subjects ingested calcium carbonate (Biotech Pharmaceuticals, Victoria, Australia) powder encased in gelatin capsules (PCCA, NSW, Australia) matched for the number of bicarbonate capsules in a chronic 0.5 g/kg BM dose on 5 occasions throughout the 3-d loading period. Similarly, with acute supplementation, placebo capsules were ingested throughout the 3 d, except for the 0.3 g/kg BM doses taken before the 2 performance trials. Each capsule dose was also coingested with 10 mL/kg BM water. A standardized pretest meal (bread with fruit spread and cereal bars; Kellogg, Melbourne, Australia) was provided to subjects before each performance trial, comprising 2372 ± 336 kJ and 1.5 g/kg BM carbohydrate. The meal was consumed 120 min before the performance trial, over a 30-min period. In previous work in our laboratory, we have demonstrated that this ingestion protocol reduces the gastrointestinal symptoms associated with bicarbonate loading.13

Experimental Trials

Testing was conducted at the Physiology Laboratory of the Australian Institute of Sport. An overview of each testing session is illustrated in Figure 2. Subjects arrived at the laboratory after an overnight fast. Each session commenced at the same time of day (6 AM) and was conducted under consistent environmental conditions. Subjects performed each test on the same type of rowing ergometer (Concept II D, Morrisville, VT) at the same time as another subject of similar ability to simulate racing conditions. Drag factor on the ergometer was set according to the Rowing Australia standards for gender, age, and weight classification. Subjects completed a 7-min standardized warm-up, adapted from a previously published protocol9 (4 min at 70% of maximal power output, followed by a 3-min period that included passive rest and 2 × 10 maximal strokes) before initiating the 2000-m test. Subjects maintained the average 500-m split time from their most recent 2000-m ergometer test for the first 250 m, and then experimenters removed the ergometer display screen from view, to minimize any effect of pacing strategies on performance. Subjects received verbal notification when they reached 500 m, 1000 m, and 1500 m, plus each 100 m of the final 500 m. Stroke rate and mean power for each 500-m split were recorded. Immediately after the completion of each performance test, subjects indicated on a scale of 6 to 20 their rating of perceived exertion for the test.

Capillary Blood Sampling and Analysis

Capillary blood samples were collected 120 min before the performance test (ie, immediately before administration of the pretest capsule dose), before the warm-up and 2 min after completion of the performance test. Before capillary blood sampling, subjects immersed one hand in warm water (~45°C) for ~1 min to increase blood flow to the area. The hand was then dried and one finger was pierced with a sterile 2.0-mm retractable lancet (Medlance, Ozorkow, Poland). The first drop of blood was removed and then 100 μL of blood was collected in a glass capillary tube (Radiometer, Copenhagen, Denmark). Blood samples were immediately analyzed for blood [HCO₃⁻] using a portable blood-gas analyzer (iSTAT, Abbott Park, IL). Blood [La⁻] was determined via analysis of an additional 20-μL sample (Lactate Pro, Arkray, Kyoto, Japan) collected at the pre-warm-up and posttest time points.

Gastrointestinal Symptoms

Subjects completed a validated questionnaire14 at the same time as each blood sample was taken (120 min before the performance test, immediately before the warm-up, and 2 min after the completion of the performance test) to quantify symptoms experienced at that time point. There were 17 items describing possible side effects associated with sodium bicarbonate ingestion,

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**Figure 2** — Schematic of testing session, illustrating timing of capillary blood sampling and GI (gastrointestinal) symptoms quantification, ingestion of capsules, standardized meal and fluid, and performance test.
including nausea, bloating, and stomach pain, and a 10-point Likert scale, ranging from 1 = no problem at all to 10 = the worst it has ever been, to indicate the severity of each symptom.

**Statistical Analysis**

A power analysis was performed to determine the sample size necessary for a crossover investigation for adequate precision with 90% confidence limits based on the smallest worthwhile change in rowing performance (0.5%).

Differences were interpreted using the ratio of the CV of each condition in relation to the thresholds for substantial difference in variability between conditions (0.9 and 1.1). Ratios >1.1 or <0.9 were considered a substantial difference between conditions.

**Effect of Interventions**

Mean values for the first and second trials in each condition were calculated for blood [HCO₃⁻] and [La⁻] at the preingestion, pretest, and posttest time points; performance (mean power and stroke rate); RPE; and GI symptoms and were entered into a spreadsheet. Pairwise comparisons were made to determine the probability that differences between conditions were greater than the smallest worthwhile change for each variable. The smallest worthwhile change was set at 0.2 of the between-group standard deviation for the placebo trial for all measures except performance, which was set at 0.5%. 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, >99%—almost certainly.

Consistent with the aforementioned likelihoods, the threshold for a substantial change was set at 75%. Results were deemed unclear if the 90% confidence interval overlapped thresholds for both the smallest worthwhile positive and negative effects.

**Reliability of Interventions**

The percentage changes in the mean and the absolute and typical percentage error between trials for each variable were calculated using an Excel spreadsheet. Individual differences in 2000-m mean power for acute and chronic sodium bicarbonate were estimated via the ratio of CVs of each condition over the placebo condition, expt was the typical percentage error calculated for placebo. Thus, by subtracting the error associated with the placebo condition, s_ind is an error-free estimate of within individual variation. Effect size was calculated to quantify the magnitude of changes in the mean between the first and second trials in each condition using an Excel spreadsheet, and differences were interpreted using the following scale: <0.2% trivial; 0.2–0.6% small; 0.6–1.2% moderate; 1.2–2.0% large.

Differences in typical error between conditions were interpreted via the ratio of the CV of each condition in relation to the thresholds for substantial difference in variability between conditions (0.9 and 1.1). Ratios >1.1 or <0.9 were considered a substantial difference between conditions.

**Results**

**Effect of Interventions**

The results of performance tests are summarized in Table 1. There were no substantial differences between conditions in either 2000-m mean power (Figure 3), stroke rate, or RPE. The highest pre-warm-up [HCO₃⁻] was observed after acute bicarbonate loading and was substantially higher than that observed in placebo and chronic bicarbonate trials. Mean posttest [HCO₃⁻] was also substantially higher with acute bicarbonate than with both placebo and chronic bicarbonate (Figure 4). Mean posttest [La⁻] after acute loading was 2.1 mmol/L higher than in the placebo trials and 1.7 mmol/L higher than with chronic bicarbonate supplementation, both of which were substantial differences. There were no clear differences in the incidence of GI symptoms between conditions at the preingestion and pre-warm-up time points, but postexercise, the incidence with acute bicarbonate was substantially lower than with chronic loading (Table 1).

**Reliability of Interventions**

The reliability of interventions for each measure is summarized in Table 1. Typical error in [HCO₃⁻] was substantially greater with acute bicarbonate compared with chronic bicarbonate (ratio of CVs = 0.40) and placebo (ratio of CVs = 0.82). The magnitudes of changes between trials for each condition were 0.1 (trivial) to 0.4 (small). For the performance measures, typical error with chronic supplementation was greater than that with acute supplementation (ratio of CVs of 0.58 and 0.85 for power and stroke rate, respectively), and the error with both bicarbonate conditions was greater than that for placebo. Individual differences in mean power were estimated to be 1.9% for acute bicarbonate and 4.6% for chronic bicarbonate.

Typical error in posttest [La⁻] was substantially greater than placebo with acute bicarbonate ingestion. There were small increases in the mean values between the first and second trials with chronic and acute conditions, and small decreases with placebo. The typical error of RPE was substantially lower with the acute loading protocol compared with chronic and placebo trials (ratio of CVs of 0.70 and 0.64, respectively), whereas the typical error of GI symptoms with chronic loading was substantially greater than that for acute and placebo conditions (ratio of CVs of 1.24 and 1.11). There were small increases in the mean RPE between the first and second trials for acute sodium bicarbonate and placebo. There also were small increases in the mean incidence of...
Table 1  Performance Test Measures, Including Mean (±SD) Values for Trial 1 (T1) and Trial 2 (T2), and Mean (90% Confidence Interval) Change in the Mean, Typical Error (TE), and Coefficient of Variation (CV). Effect Size (Value and Magnitude) Is Also Shown.

<table>
<thead>
<tr>
<th>Variable</th>
<th>T1, mean ± SD</th>
<th>T2, mean ± SD</th>
<th>Absolute change in mean (90% CI)</th>
<th>Absolute TE (90% CI)</th>
<th>CV (%) (90% CI)</th>
<th>Effect Size</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>T1, mean ± SD</td>
<td>T2, mean ± SD</td>
<td>Absolute change in mean (90% CI)</td>
<td>Absolute TE (90% CI)</td>
<td>CV (%) (90% CI)</td>
<td>Value</td>
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<tr>
<td>Placebo</td>
<td></td>
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<tr>
<td>induced alkalosis [HCO₃⁻] (mmol/L)</td>
<td>26.6 ± 2.7</td>
<td>27.8 ± 2.2</td>
<td>1.3 (–0.47 to 2.98)</td>
<td>1.7 (1.2 to 3.3)</td>
<td>6.0 (4.1 to 11.9)</td>
<td>0.4</td>
</tr>
<tr>
<td>2000-m mean power (W)</td>
<td>278 ± 59</td>
<td>277 ± 61</td>
<td>–1.0 (–6 to 3)</td>
<td>5 (3 to 9)</td>
<td>1.6 (1.1 to 3.0)</td>
<td>0.0</td>
</tr>
<tr>
<td>2000-m stroke rate (strokes/min)</td>
<td>31 ± 3</td>
<td>32 ± 3</td>
<td>0.7 (–0.1 to 1.5)</td>
<td>1 (1 to 2)</td>
<td>2.7 (1.8 to 5.1)</td>
<td>0.2</td>
</tr>
<tr>
<td>perceived exertion (6–20)</td>
<td>18 ± 2</td>
<td>19 ± 1</td>
<td>1.0 (–0.2 to 2.2)</td>
<td>1 (1 to 2)</td>
<td>6.9 (4.7 to 13.7)</td>
<td>0.5</td>
</tr>
<tr>
<td>posttest [La⁻] (mmol/L)</td>
<td>13.7 ± 1.8</td>
<td>13.3 ± 2.3</td>
<td>–0.4 (–1.2 to 0.4)</td>
<td>0.7 (0.5 to 1.5)</td>
<td>6.1 (4.1 to 13.2)</td>
<td>0.2</td>
</tr>
<tr>
<td>GI symptoms (rating)</td>
<td>27 ± 10</td>
<td>25 ± 6</td>
<td>–2 (–6 to 1)</td>
<td>4 (3 to 7)</td>
<td>10.5 (7.2 to 21.2)</td>
<td>0.2</td>
</tr>
<tr>
<td>Acute bicarbonate</td>
<td></td>
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<tr>
<td>induced alkalosis [HCO₃⁻] (mmol/L)</td>
<td>32.4 ± 2.1</td>
<td>31.9 ± 2.2</td>
<td>–0.5 (–2.9 to 1.9)</td>
<td>2.4 (1.7 to 4.6)</td>
<td>7.3 (5.0 to 14.5)</td>
<td>0.2</td>
</tr>
<tr>
<td>2000-m mean power (W)</td>
<td>279 ± 64</td>
<td>281 ± 67</td>
<td>2.4 (–3.8 to 8.6)</td>
<td>6 (4 to 12)</td>
<td>2.1 (1.4 to 4.0)</td>
<td>0.0</td>
</tr>
<tr>
<td>2000-m stroke rate (strokes/min)</td>
<td>31 ± 4</td>
<td>32 ± 4</td>
<td>0.7 (–0.4 to 1.8)</td>
<td>1 (1 to 2)</td>
<td>3.4 (2.3 to 6.6)</td>
<td>0.2</td>
</tr>
<tr>
<td>perceived exertion (6–20)</td>
<td>18 ± 1</td>
<td>19 ± 1</td>
<td>0.7 (–0.1 to 1.5)</td>
<td>1 (1 to 2)</td>
<td>4.4 (3.0 to 8.6)</td>
<td>0.4</td>
</tr>
<tr>
<td>posttest [La⁻] (mmol/L)</td>
<td>15.4 ± 2.0</td>
<td>15.9 ± 2.3</td>
<td>0.5 (–0.6 to 1.6)</td>
<td>1.1 (0.8 to 2.2)</td>
<td>7.0 (4.8 to 13.8)</td>
<td>0.2</td>
</tr>
<tr>
<td>GI symptoms (rating)</td>
<td>24 ± 8</td>
<td>25 ± 7</td>
<td>1 (1 to 3)</td>
<td>2 (1 to 5)</td>
<td>9.5 (6.3 to 20.9)</td>
<td>0.2</td>
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<tr>
<td>Chronic bicarbonate</td>
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<tr>
<td>induced alkalosis [HCO₃⁻] (mmol/L)</td>
<td>28.1 ± 2.8</td>
<td>27.9 ± 2.8</td>
<td>–0.2 (–1.0 to 0.5)</td>
<td>0.8 (–1.0 to 0.5)</td>
<td>2.9 (2.0 to 5.7)</td>
<td>0.1</td>
</tr>
<tr>
<td>2000-m mean power (W)</td>
<td>285 ± 68</td>
<td>279 ± 62</td>
<td>–1.5 (–5.0 to 2.2)</td>
<td>9 (6 to 17)</td>
<td>3.6 (2.5 to 7.0)</td>
<td>0.1</td>
</tr>
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<td>25 ± 10</td>
<td>–2 (–6 to 2)</td>
<td>4 (2 to 7)</td>
<td>11.8 (8.0 to 23.9)</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Effect size value: Changes in the mean between the first and second trials in each condition.\(^{17}\)

Effect size magnitude: Value interpreted using the scale <0.2% trivial; 0.2–0.6% small; 0.6–1.2% moderate; and 1.2–2.0% large.\(^{18}\)
Figure 3 — Ergometer power output (mean ± SD) for each 500-m section of the 2000-m time trials (n = 7).

Figure 4 — Mean (±SD) blood bicarbonate concentration at pre-ingestion, pre-warm-up and posttest time points (n = 7).
GI symptoms between the first and second trials for acute supplementation, but small decreases for the chronic and placebo conditions.

Discussion

Overall, neither the chronic nor acute bicarbonate loading enhanced rowing performance of our subjects. This study is the first systematic assessment of the effect and reliability of induced blood alkalosis on subsequent 2000-m ergometer rowing performance using two sodium bicarbonate ingestion protocols. The primary finding was that the reliability of mean power output in 2000-m rowing ergometer efforts was −3% with both acute and chronic bicarbonate ingestion. Secondary findings indicated that postsupplementation blood [HCO₃⁻] is associated with typical error of −3% for chronic bicarbonate loading and −7% for acute loading.

Performance

We were surprised that neither of the bicarbonate loading protocols enhanced rowing ergometer performance, despite the achievement of a substantial alkalosis with the acute bicarbonate protocol. Systematic evaluation of the literature suggests there should be at least some association between enhanced buffering potential and performance. Indeed, a previous investigation of rowing ergometer performance after acute bicarbonate loading reported positive effects. Although this conflicts with the results of the current investigation, the findings of a recent meta-analysis conducted in our laboratory provide a potential explanation for the discrepancy. Specifically, the effect of bicarbonate supplementation on performance in highly trained athletes is 1.7% (90% confidence limits, ±2.0%). Furthermore, there is a 1.1% (±1.1%) reduction in this result, to a 0.6% enhancement of performance, for subjects of a lower standard. Our subjects were club-level rowers, and therefore of a lower caliber than the national rowing team members recruited for the previous study.

In our investigation, postexercise [HCO₃⁻] was substantially higher than other conditions with acute bicarbonate, but the fact that RPE values with this treatment were not substantially different from the other conditions suggests that athletes of a lower caliber may not be able to make use of additional blood-buffering capacity and enhance their performance. Furthermore, the recent meta-analysis specifies that performance outcomes can be diminished with increased exercise duration. The previous investigation used a 6-min test to simulate a 2000-m on-water race, whereas we replicated racing conditions by simulating the same distance on the ergometer, and most subjects completed the test in over 7 min. Moreover, another study similar to the current investigation has also reported no improvement in rowing performance with bicarbonate ingestion. Therefore, findings of the current investigation are consistent with some previous literature, as well as with the findings of a recent meta-analysis of the performance “benefits” of bicarbonate loading.

Reliability

The typical error values that we reported for mean power in 2000-m rowing efforts (−3% for bicarbonate loading and 1.6% for placebo) are consistent with the only previous investigation of the reliability of 2000-m rowing ergometer performance, in which a typical error in mean power of 2.0% (95% confidence interval, 1.3–3.1%) was reported. Our typical error values for this rowing ergometer test also compare favorably with those in most time trials, including cycle ergometer, treadmill, and track running tests, where the typical error expressed as a CV is −1–5%. Our typical error results are also consistent with those of studies that have examined the reliability of mean power in tests of maximal rowing ergometer performance, which have been of shorter duration and higher intensity, but have used the same type of ergometer (Concept II) as in the current investigation. A similar CV to the current investigation was reported (3.1%) in a 90-s rowing test. Collectively, the current study and relevant literature suggest that the reliability of rowers’ ergometer performance is not compromised by prior ingestion of sodium bicarbonate.

An interesting finding of this investigation was the relatively poor reliability of induced blood alkalosis after acute bicarbonate ingestion in comparison with that of performance. Reproducibility of [HCO₃⁻] values after buffer ingestion has not previously been investigated; however, the technical error of the iSTAT analyzer (used in this investigation to measure [HCO₃⁻]), has been reported to be relatively low (~2.5%). Intraindividual variation with repeated trials increases when there is a large biological error component, which can be due to changes in an athlete’s physical state. A potential source of biological error in the current investigation was subjects’ experience of gastrointestinal symptoms. The relatively high within-subject variability of gastrointestinal symptoms suggests that athletes should be aware that the severity of potential symptoms can vary when they use sodium bicarbonate on different occasions. Furthermore, even when athletes are familiarized to bicarbonate supplementation via trials conducted in training, there still exists the possibility that gastrointestinal distress can manifest in a competition setting. Sport scientists should also be aware of the implications of the relatively high variability inherent in repeated acute sodium bicarbonate loading. The typical error associated with [HCO₃⁻] after acute bicarbonate loading was 2.4 mmol/L meaning that for an observed blood [HCO₃⁻] of 30 mmol/L, the 95% confidence interval will be 25.3 to 34.7 mmol/L. The practical importance of this finding is that a sport scientist would need to find a large change in [HCO₃⁻] measurements (>10 mmol/L) after a specific acute bicarbonate loading protocol before it can be interpreted as a better protocol.

Blood lactate concentration [La⁻] measured after performance test completion in the sodium bicarbonate conditions elicited typical errors of −7%. The relatively high variability of [La⁻] after high-intensity exercise in comparison with other experimental variables, such as
power output, is an observation consistent with previous research. It should be acknowledged that the typical error associated with posttest blood lactate measurements is partly due to the technical error of the blood lactate analyzer used. Reliability of the Lactate Pro analyzer, which was used in the current investigation, has recently been reported to be $\sim 4\%$ for $[\text{La}^-]$ recorded after maximal exercise. The large uncertainty of any measure of blood lactate is rarely mentioned when it comes to interpretation of shifts in blood lactate curves, but should be taken into account for clarity.

**Practical Applications of Reliability Testing**

The estimation of individual differences and typical error values in 2000-m mean rowing power can aid in the interpretation of mean group results and individual performance observations. The mean difference in performance between acute bicarbonate and placebo was 0.9% and individual differences from mean responses were estimated to be 1.9%. Comparing these two results suggests that although some individuals would produce more power with acute bicarbonate compared with placebo, most would show little or no change and some would produce less power. The individual differences estimate can also be used to devise confidence limits for observed performances of an individual athlete, giving coaches an indication of the range of the true value and a yardstick against which to judge whether observed differences in performance are real. For example, an observed 2000-m effort for a particular athlete can be assumed to lie within a range that is $\pm 1.9\%$ of the observed value at a 68% level of confidence, and $\pm 3.7\%$ at a 95% level of confidence. Such examples provide a basis for the calculation of confidence limits using estimates of individual differences, but the current investigation is limited by the relatively small sample size, and more precise estimates are needed via reliability studies that have larger sample sizes.

Sample size ($n$) can be estimated via the equation $n = 8s^2/d^2$, where $s$ is the typical error and $d$ is the smallest worthwhile change in performance. The smallest worthwhile change is approximately 0.5 of the typical error, which for acute bicarbonate in the current investigation was 1.1\% ($0.5 \times 2.1\%$). From the results of the current investigation, the recommended sample size is $8(2.1)^2/(1.05)^2 = 32$ subjects. Given that subject numbers need to be quadrupled from that required for a simple study to estimate individual differences, the required sample size is greater than could be realistically used by most researchers ($32 \times 4 = 128$); nevertheless, these calculations provide directions for future reliability studies that can provide more precise estimates of individual differences.

A limitation of this study was that the first and second trials in the chronic loading condition were performed under slightly different conditions (1 d of loading for the first trial and 3 d for the second trial). However, the CV for induced alkalosis after chronic loading was substantially lower than that for acute loading; therefore, it seems that the different conditions did not have an adverse effect on the reliability of induced alkalosis. Furthermore, we scheduled the repeated trials 48 h apart to replicate the repeated racing efforts that rowers exert in a regatta. While we have demonstrated that ergometer sessions timed similarly to regatta races can be highly reproducible, it is difficult to transfer the findings to on-water racing due to the influence of variables such as environmental conditions. Future studies should investigate the reliability of on-water efforts after sodium bicarbonate ingestion, which would have greater construct validity.

The heterogeneity of our subject population was increased by the inclusion of male and female subjects, which should be considered when applying findings of this investigation to different athlete populations. Our subjects were experienced rowers who were skilled with 2000-m ergometer performance tests, but females can be less reliable in repeated performance efforts than males, which is partially due to the influence of the menstrual cycle. Potentially, a group of highly trained male rowers would be more able to produce consistent performances, and therefore the typical variation and individual differences from performances would be expected to be lower. These differences should be acknowledged when providing feedback to elite rowers about observed changes in 2000-m ergometer power.

**Conclusions**

In the current investigation, acute and chronic bicarbonate loading had only trivial effects on 2000-m rowing ergometer performance. However, there was a high reliability of individual responses to bicarbonate loading. Furthermore, responses were less variable with chronic in comparison with acute loading. Athletes should understand that, owing to the high reliability of rowing ergometer performance with bicarbonate loading, the magnitude of any performance improvement or decrement is likely to be repeated with subsequent trials.

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