Effects of Sodium Bicarbonate Ingestion on Prolonged Intermittent Exercise

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ABSTRACT

PRICE, M., P. MOSS, and S. RANCE. Effects of Sodium Bicarbonate Ingestion on Prolonged Intermittent Exercise. Med. Sci. Sports Exerc., Vol. 35, No. 8, pp. 1303–1308, 2003. Purpose: The aim of this study was to determine the effects of sodium bicarbonate ingestion on prolonged intermittent exercise and performance. Methods: Eight healthy male subjects (mean ± SD: age 25.4 ± 6.4 yr, mass 70.9 ± 5.1 kg, height 179 ± 7 cm, VO₂max 4.21 ± 0.51 L·min⁻¹) volunteered for the study, which had received ethical approval. Subjects undertook two 30-min intermittent cycling trials (repeated 3-min blocks; 90 s at 40% VO₂max, 60 s at 60% VO₂max, 14-s maximal sprint, 16-s rest) after ingestion of either sodium bicarbonate (NaHCO₃; 0.3 g·kg⁻¹) or sodium chloride (NaCl; 0.045 g·kg⁻¹). Expired air, blood lactate (BLa), bicarbonate (HCO₃⁻), and pH were measured at rest, 30 and 60 min postingestion, and during the 40% VO₂max component of exercise (4, 10, 16, and 29 min). Results: After ingestion, pH increased from rest to 7.46 ± 0.03 and 7.40 ± 0.01 for NaHCO₃ and NaCl, respectively (main effect for time and trial; P < 0.05). Values decreased at 15 min of exercise to 7.30 ± 0.07 and 7.21 ± 0.06, respectively, remaining at similar levels until the end of exercise. BLa peaked at 15 min (12.03 ± 4.31 and 10.00 ± 2.58 mmol·L⁻¹, for NaHCO₃ and NaCl, respectively; P > 0.05) remaining elevated until the end of exercise (P < 0.05). Peak power expressed relative to sprint 1 demonstrated a significant main effect between trials (P < 0.05). Sprint 2 increased by 11.5 ± 5% and 1.8 ± 9.5% for NaHCO₃ and NaCl, respectively. During NaHCO₃, sprint 8 remained similar to sprint 1 (0.2 ± 17%), whereas a decrease was observed during NaCl (~10.0 ± 16.0%). Conclusion: The results of this study suggest that ingestion of NaHCO₃ improves sprint performance during prolonged intermittent cycling. Key Words: BLOOD LACTATE, PH, ALKALOSIS, PEAK POWER, PERFORMANCE, RPE

The ingestion of sodium bicarbonate between 1 and 3 h before exercise has been shown to increase the body’s alkaline reserve (7,20) in an attempt to try and improve anaerobic performance. Studies examining such an effect on sprint performance have demonstrated both positive effects (2,22) and no effects (13,18) on performance outcomes.

More recently studies have examined the effects of bicarbonate ingestion upon more prolonged type exercise (7,20). For example, Galloway and Maughan (7) examined 1 h of cycle exercise at 70% VO₂max after either bicarbonate or placebo (CaCO₃) ingestion. The results indicated that the induced alkalosis increased lactate efflux from muscle although the effects on performance were not examined. Stephens et al. (20) examined a similar duration protocol involving two exercise intensities (30 min at 77% VO₂max, followed by completion of a known amount of work at ~80% VO₂max, ~30 min), concluding that bicarbonate ingestion did result in a relatively small muscle alkalosis but with no effect on muscle metabolism or intense endurance performance.

Although the above studies have examined exercise of longer durations, the protocols employed have not represented exercise patterns typically experienced by those involved in team sports, i.e., intermittent exercise. Prolonged intermittent exercise protocols reported in the literature typically include exercise intensities representative of walking, jogging/cruising, and sprinting (5,17,19) and produce blood lactate values that are significantly greater than for continuous exercise of a matched energy expenditure and duration (3). As existing prolonged exercise studies of bicarbonate ingestion have suggested increased lactate efflux during longer exercise durations (7,20), this may be beneficial to intermittent exercise where greater rates of anaerobic energy production occur with corresponding alterations to muscle homeostasis (3). Therefore, the aim of this study was to examine the effects of bicarbonate ingestion upon prolonged intermittent exercise and performance.
METHODS

Eight healthy male subjects (mean ± SD: age 25.4 ± 6.4 yr, body mass 70.9 ± 5.1 kg, height 179 ± 9 cm, VO\textsubscript{2max} 4.21 ± 0.51 L·min\textsuperscript{-1}) volunteered for the study, which had received University Ethics Committee Approval. All subjects were moderately trained, undertaking aerobic exercise three times each week. Each subject was asked to refrain from caffeine, alcohol, and exercise for 24 h before each trial and gave written informed consent to participate. Trials were carried out at the same time of each day with at least 7 d between trials.

Subjects visited the laboratory on three separate occasions. On the first visit, subjects completed an incremental cycle ergometer test for VO\textsubscript{2max} (Monark 824E, Varberg, Sweden). The test involved four initial submaximal exercise stages of 4-min duration (35, 70, 105, and 140 W) followed by workload increases of 35 W every 3 min until volitional exhaustion. A cadence of 70 rev·min\textsuperscript{-1} was maintained throughout exercise. The submaximal exercise stages were undertaken in order for exercise loads of 40% and 60% VO\textsubscript{2max} to be accurately determined for the intermittent exercise trials. Expired air was collected via the Douglas bag technique during the final minute of each submaximal and incremental exercise stage. Samples were analyzed for oxygen and carbon dioxide content (Servomex, Crowborough, England) and expired air volume (Harvard dry gas meter, Harvard Apparatus, Kent, England) with values for oxygen consumption (VO\textsubscript{2}) and carbon dioxide production (VCO\textsubscript{2}) subsequently calculated. Heart rate was recorded during the final 15 s of each workload (Polar Electro, Kempele, Finland).

On subsequent visits to the laboratory, subjects undertook 30 min of intermittent cycle exercise 1 h after ingestion of either sodium bicarbonate (NaHCO\textsubscript{3}; 0.3 g·kg\textsuperscript{-1}) or sodium chloride (NaCl; 0.045 g·kg\textsuperscript{-1}). The dosages employed enabled drinks to be matched by taste. Furthermore, the NaHCO\textsubscript{3} dosage has been previously reported to produce positive effects on cycling performance without gastrointestinal discomfort (14,15). The order of testing was randomized, counterbalanced, and single blind. The intermittent exercise protocol involved 10 repeated 3-min blocks of exercise based on soccer notational analysis (19). Although cycle ergometry is not the exact exercise mode undertaken by team sports players, it does allow for the safe, precise, and rapid application of different workloads, particularly high-intensity workloads, during exercise. Each 3-min block consisted of 90 s at 40% VO\textsubscript{2max}, 60 s at 60% VO\textsubscript{2max}, 14-s maximal sprint, and 16-s active rest (Fig. 1). The maximal sprint was undertaken using the standard Wingate anaerobic test load (7.5 g·kg\textsuperscript{-1} body weight) and procedures (11). Before each sprint, subjects continued pedalling on the unloaded ergometer while the appropriate sprint loading was applied to the ergometer cradle. This ordinarily took 3–5 s, was consistent between trials, and was the only time when any unloaded cycling occurred. On completion of each sprint, subjects continued pedalling at a resistance equal to 40% VO\textsubscript{2max} before beginning the subsequent 3-min exercise block. A cadence of 70 rev·min\textsuperscript{-1} was maintained throughout the 30-min protocol except for the maximal sprint where subjects were encouraged to sprint as fast as possible in accordance with test procedures.

Expired air was collected via the Douglas bag technique at rest preingestion (−60 min), at rest 60 min postingestion (0 min), and during minutes 3:30–4:30, 9:30–10:30, 15:30–16:30, and 27:30–28:30 of exercise. Heart rate was recorded at 1:30 min and during the final 15 s of each expired air collection. These collection periods corresponded to the 40%VO\textsubscript{2max} component of each exercise block. Although, due to the nature of the intermittent protocol, steady-state values would not be achieved, the current design allowed monitoring of respiratory gases and related parameters during consistent and equal exercise intensities. Ratings of perceived exertion (RPE, Borg scale) (1), gut fullness (GF; 1–5 Likert scale), and abdominal discomfort (AD; 1–5 Likert scale) were also recorded during the final 15 s of each expired air sample. Fingertip arterialized capillary blood samples were collected for analysis of pH, HCO\textsubscript{3}\textsuperscript{-} (ABL5 Radiometer, Copenhagen, Denmark) and blood lactate (BL\textsubscript{a}; Analox GM7, Analox Instruments, Surrey, England) preingestion, 30 and 60 min postingestion, and during each expired air sample. This enabled values to be taken after each sprint and effectively during consistent active recovery. For each sprint peak power output (PPO), minimum power output (MinPO) and mean power output (MPO) were recorded. Fatigue index (FI; %) was calculated for each sprint from the difference between PPO and MinPO, expressed as a percentage of PPO for that sprint. To overcome individual variation in sprint performance, PPO data for each subject was also expressed relative to the initial sprint (PPOrel).

FIGURE 1—Schematic representation of the intermittent protocol. Each exercise block was 3 min in duration (top section) with each 3-min block comprising 90 s at 40% VO\textsubscript{2max}, 60 s at 60% VO\textsubscript{2max}, 14-s maximal sprint, and 16-s active rest (bottom section).
Data were analyzed by two-way analysis of variance with repeated measures on both factors (trial × time). Significance was accepted at the P < 0.05 level unless otherwise stated. All data are expressed as mean ± SD. The relationship between selected physiological, perceptual, and performance variables was also analyzed (Pearson’s r).

**RESULTS**

No differences were observed between trials for oxygen consumption (VO₂; P > 0.05). VO₂ at 4 (2.28 ± 0.23 and 2.21 ± 0.18 L-min⁻¹) and 29 min of exercise (2.40 ± 0.18 and 2.43 ± 0.27 L-min⁻¹, for NaHCO₃ and NaCl, respectively, P < 0.05) were equivalent to 54.7 ± 8.9 and 53.0 ± 8.1% VO₂max and 57.0 ± 8.7 and 58.3 ± 10.4% VO₂max, respectively.

RER immediately before exercise was similar between trials (0.80 ± 0.05 and 0.83 ± 0.08, for the NaHCO₃ and NaCl trials, respectively). Values were greatly elevated to 1.33 ± 0.14 and 1.37 ± 0.11 at 4 min of exercise, respectively (Fig. 2; P < 0.05), although not different between trials. Values then decreased by 11 min where they remained stable until the end of the exercise period (1.04 ± 0.05 and 1.05 ± 0.07, for the NaHCO₃ and NaCl trials, respectively).

Heart rates were similar between trials. During the 40% VO₂peak component of each 3-min block of exercise, heart rate gradually increased from 142 ± 22 and 140 ± 21 beats-min⁻¹ at 8 min to 154 ± 19 and 154 ± 17 at 29 min for the NaHCO₃ and NaCl trials, respectively. After the first sprint, heart rates were 162 ± 17 and 161 ± 14, increasing to 175 ± 15 and 175 ± 15 beats-min⁻¹ after sprint 10, respectively.

No differences were observed for PPO between trials. However, a significant main effect between trials was observed for PPOrel with values being greater for the NaHCO₃ trial (P < 0.05). F1 also demonstrated a significant main effect between trials (P < 0.01) with greater values (greater fatigue) during the NaHCO₃ trial. Values approached significance for MinPO (main effect, P = 0.079). When expressed relative to the first sprint (902 ± 179 and 914 ± 158 W, for NaHCO₃ and NaCl, respectively, P > 0.05), power output was greater throughout exercise during the NaHCO₃ trial when compared with decreases in PPO for the NaCl trial (main effect between trials, P < 0.05; Fig. 3). No differences were observed between trials for maximal cadence or total work done over the 10 sprints (69.7 ± 10.3 and 71.0 ± 12.3 kJ, for NaHCO₃ and NaCl, respectively).

Resting pH was similar for both trials before ingestion (7.41 ± 0.02 and 7.41 ± 0.01, for NaHCO₃ and NaCl, respectively, P > 0.05; Fig. 4). Values for the NaHCO₃ trial then gradually increased until immediately before exercise (7.46 ± 0.03; P < 0.05) when compared with no change for the NaCl trial (7.40 ± 0.01; P > 0.05). During exercise, values decreased quickly during the first 5 min in both trials decreasing further until 15 min (7.30 ± 0.07 and 7.21 ± 0.06, for NaHCO₃ and NaCl, respectively; P < 0.05). Values then remained at similar levels until the end of exercise (7.29 ± 0.07 and 7.21 ± 0.05, for NaHCO₃ and NaCl, respectively; P < 0.05). A difference between trials of

**FIGURE 2**—RER at rest and during 30-min prolonged intermittent exercise during NaHCO₃ and NaCl trials (⁎ denotes significant difference in relation to rest for both trials).

**FIGURE 3**—Peak power output relative to the first sprint during NaHCO₃ and NaCl trials (⁎ denotes significant main effect between trials).

**FIGURE 4**—Blood pH at rest, during 60-min ingestion, and 30-min intermittent exercise for the NaHCO₃ and NaCl trials (Significant main effects for between trials and time).
0.43 mmol·exercise being similar between trials (0.94 affected by ingestion, with values immediately before ex-

No differences were observed between PPO and pH or PPO and bicarbonate concentration for either trial.

No significant interaction was observed for BLA (P > 0.05) although the main effect between trials approached significance (P = 0.081; Fig. 5). Resting values were not affected by ingestion, with values immediately before exercise being similar between trials (0.94 ± 0.32 and 1.09 ± 0.43 mmol·L⁻¹, for the NaHCO₃ and NaCl trials, respectively). BLA increased steadily during exercise until 15 min (12.03 ± 4.31 and 10.00 ± 2.58 mmol·L⁻¹, respectively), remaining elevated until the end of exercise (11.85 ± 3.51 and 10.36 ± 1.64 mmol·L⁻¹). The correlation between pH and BLA during the NaCl and NaCl trials were r = −0.884 and r = −0.930, respectively (P < 0.01).

Increases in RPE were observed over time for both trials with values reaching 14.9 ± 1.7 and 15.3 ± 1.2 at 29 min (P < 0.05). No differences were observed between trials. GF and AD increased during the 1-h absorption period and remained elevated throughout the exercise period (Table 1). No differences were observed between trials for RPE or AD. A significant main effect was observed for GF with greater fullness observed for the bicarbonate trial. RPE was related to pH but more strongly to bicarbonate concentration (Table 2). RPE was also related to GF and AD during the NaHCO₃ trial but only to AD during the NaCl trial.

DISCUSSION

The main finding of this study was that ingestion of sodium bicarbonate enabled sprint performance to be main-
tained at a level similar to the initial stages of exercise during 30 min of prolonged intermittent exercise. Resting pH values pre- and postingestion were similar to previous studies (10,12,18) with ingestion resulting in an increase of 0.06 pH units, also similar to previous studies (2,6,16). A state of metabolic alkalosis was therefore achieved after 1 h postingestion as observed by previous authors.

During the exercise period, the difference in pH between trials due to alkalosis was maintained and even increased slightly. The maintenance of this greater pH has been ob-
served for short-duration repeated sprint exercise (10 × 6-s sprints) (6) but, to the authors knowledge, this is the first study to report such as response during more prolonged intermittent exercise with a significant sprint component. After 30 min of exercise pH for the NaHCO₃ trial was 7.29, whereas for the NaCl trial values decreased to 7.21. Such pH values, particularly those for the NaCl trial, are therefore in line with those considered to represent metabolic acidosis (≤7.28) (8). These results suggest that although decreases in pH from resting values are not prevented by NaHCO₃ ingestion, this procedure does provide a more alkalotic inter-

Blood lactate at rest and during 30-min intermittent exercise for the NaHCO₃ and NaCl trials.

When expressed relative to the initial sprint, power output during the NaHCO₃ trial was maintained above (sprints 2–5) or at a similar level (sprints 6–10) to the first maximal effort. This was not observed for the NaCl trial, where sprints 3–9 were below that of the initial effort. As noted earlier, this initial 15-min period was when pH was decreasing. Once the pH level stabilized, improvements in PPO were much less. This may be due to the lower absolute pH during the latter 15 min of exercise affecting muscle con-
traction ability (4) or that prior bicarbonate ingestion may be more effective during the first 15 min of intermittent exercise when homeostasis is in a state of flux.

The data for each sprint demonstrated that both PPOrel and FI were greater for the NaHCO₃ trial when compared with that for the NaCl trial. However, maximal cadence for each sprint during both trials was similar. As each sprint involves acceleration of the flywheel during the initial sec-

FIGURE 5—Blood lactate at rest and during 30-min intermittent exercise for the NaHCO₃ and NaCl trials.
maximal cadence earlier during each sprint. (i.e., greater acceleration). Furthermore, as MinPO tended to be lower for the NaHCO3 trial, this would indicate that the greater acceleration may have resulted in not only greater PPO but also the greater fatigue during each sprint for the NaHCO3 trial. This would be consistent with the similar total work done during both protocols. However, as PPOrel was initially improved and then maintained during the NaHCO3 trial, bicarbonate ingestion may be important in aiding recovery between sprints throughout the intermittent protocol as well as enhancing the attainment of PPO. Unlike previous sprint research (6), little relationship was observed between PPO and pH and suggests that other limiting factors may be at work during prolonged intermittent exercise.

An interesting finding was that during the first 5 min of exercise. RER values were considerably greater than 1.00, indicating a significant anaerobic component to the energy provision of the exercise period. Values then returned to near 1.0 by 11 min of exercise and remained at similar levels for the final 20 min of the exercise period. As the expired air samples were collected between approximately 30 and 90 s after each sprint had been undertaken, it is possible that these values may represent excess CO2 from buffering of lactic acid produced during each sprint. However, as BLA remained constant during the final 15 min of exercise, the data do not suggest that there was any imbalance between BLA production and removal from the additional sprints. The initial peak in RER therefore probably represents the extra anaerobic cost of the initiation of exercise, superimposed on the anaerobic cost of the first sprint. Furthermore, as the “overall” exercise intensity was 55–60% VO2max, and similar to previous intermittent protocols (3), this may indicate that a combination of submaximal workload components within the protocol enabled both sufficient wash-out of metabolites from the active muscle and sufficient aerobic metabolism for conversion of lactate to pyruvate. Protocols employing longer work to rest durations, which result in greater BLA responses (3), may therefore benefit from bicarbonate ingestion to a greater extent when compared to those employing shorter work: rest durations.

When considering the perceptual data, the present study provides a useful insight into the relationships between RPE, physiological variables, and those of gut fullness and abdominal discomfort. RPE was related to pH during both trials but was more strongly related to bicarbonate concentration. Swank and Robertson (23) observed that RPE may be related to the buffering capacity of the blood when reporting attenuation of local, chest, and overall RPE with alkalosis. In the present study, however, RPE was similar between trials and does not support the results of Swank and Robertson even though alkalosis had been achieved before exercise. Furthermore, both gut fullness and abdominal discomfort were both related to RPE during the NaHCO3 trial but more strongly during the NaCl trial, suggesting that factors related to ingestion of alkali and the alkalinization procedure are more closely related to RPE. This may also reflect the intermittent nature of the exercise protocol employed when compared with Swank and Robertson who employed 3 × 5-min (90% VO2max) exercise blocks with 10-min recovery between them. The sprint component and continuous, prolonged nature of the present studies’ protocol may have accentuated the discomfort of a full gut.

In conclusion, this study has shown that bicarbonate ingestion does initially improve and then maintain sprint performance during prolonged intermittent type exercise. The improvements in performance occurred over the initial 15 min of exercise, which is consistent with the time period when blood pH was changing rapidly. Bicarbonate ingestion may therefore improve performance during prolonged intermittent type exercise when pH is decreasing and over a greater exercise duration than previously considered.

### Table 1. Ratings of perceived exertion (RPE), gut fullness (GF), and abdominal discomfort (AD) during NaHCO3 and NaCl trials.

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<th>Time (min)</th>
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<tr>
<td></td>
<td>NaHCO3</td>
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<tr>
<td>RPE*</td>
<td>—</td>
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<tr>
<td>GF§</td>
<td>2.5 ± 0.8</td>
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<tr>
<td>AD§</td>
<td>2.5 ± 0.8</td>
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Values are means ± SD, N = 8.

* Significant main effect for time, at 0.05 level.

§ Significant main effect for time and trial, at 0.05 level.

### Table 2. Correlations coefficients between ratings of perceived exertion (RPE; Borg scale) and selected physiological parameters.

<table>
<thead>
<tr>
<th></th>
<th>NaHCO3 Trial</th>
<th>NaCl Trial</th>
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<tbody>
<tr>
<td>RPE vs pH</td>
<td>-0.488*</td>
<td>-0.571*</td>
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<tr>
<td>RPE vs bicarbonate</td>
<td>-0.627*</td>
<td>-0.807*</td>
</tr>
<tr>
<td>RPE vs GF</td>
<td>0.527*</td>
<td>0.332</td>
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<tr>
<td>RPE vs AD</td>
<td>0.582*</td>
<td>0.540*</td>
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</tbody>
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Values are means ± SD, N = 8.

* Significant at 0.01 level.
REFERENCES


