Sodium bicarbonate improves 4 km time trial cycling performance when individualised to time to peak blood bicarbonate in trained male cyclists

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Title: Sodium bicarbonate improves 4 km time trial cycling performance when individualised to time to peak blood bicarbonate in trained male cyclists.

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Abstract

The aim of this study was to investigate the effects of sodium bicarbonate ($NaHCO_3$) on 4 km cycling time trial (TT) performance when individualised to a predetermined time to peak blood bicarbonate (HCO_3^-). Eleven male trained cyclists volunteered for this study (height 1.82 ± 0.80 m, body mass (BM) 86.4 ± 12.9 kg, age 32 ± 9 years, peak power output (PPO) 382 ± 22 W). Two trials were initially conducted to identify time to peak HCO_3^- following both 0.2 $g \cdot kg^{-1}$ BM (SBC2) and 0.3 $g \cdot kg^{-1}$ BM (SBC3) $NaHCO_3$. Thereafter, on three separate occasions using a randomized, double-blind, crossover design, participants completed a 4 km TT following ingestion of either SBC2, SBC3, or a taste-matched placebo (PLA) containing 0.07 $g \cdot kg^{-1}$ BM sodium chloride (NaCl) at the predetermined individual time to peak HCO_3^-. Both SBC2 (-8.3 ± 3.5 s; $p < 0.001$, $d = 0.64$) and SBC3 (-8.6 ± 5.4 s; $p = 0.003$, $d = 0.66$) reduced the time to complete the 4 km TT, with no difference between SBC conditions (mean difference = 0.2 ± 0.2 s; $p = 0.87$, $d = 0.02$). These findings suggest trained cyclists may benefit from individualising $NaHCO_3$ ingestion to time to peak HCO_3^- to enhance 4 km TT performance.

Key words: buffering, metabolic alkalosis, dosage, individual pursuit

Introduction

Competitive cycling is reflective of high-intensity exercise, particularly in events such as the individual and team pursuit, which entails completion of a 4 km time trial (TT). The typical duration of this event ranges between 4 (world record times) and 7 min (recreational riders), and because of this, a large energy supply is provided by anaerobic glycolysis (Gastin, 2001). With such a demand an exponential accumulation of metabolites including inorganic phosphate, hydrogen ions (H^+), and lactate occurs (Westerblad et al., 2002; Allen et al., 2008). Due to the inverse relationship between H^+ and pH, this process causes metabolic acidosis and results in a decrease in blood and muscle pH (Allen et al., 2008). Whilst there is no singular mechanism of peripheral fatigue, perturbations to acid base balance have been implicated to inhibit enzyme activity (e.g. glycogen phosphorylase) and calcium ion (Ca^{2+}) cross-bridge binding (Fitts, 2008, 2016). Preventative strategies such as the ingestion of nutritional ergogenic aids may therefore be beneficial to mitigate such local acid-base disturbances in active musculature (Christensen, Shirai, Ritz, & Nordsborg, 2017; Matson & Tran, 1993).

Ingestion of sodium bicarbonate ($NaHCO_3$), a known buffering agent, can reinforce acid base balance by producing a state of metabolic alkalosis (increased pH and HCO_3^-) (McNamara & Worthley, 2001). Increases in pH typically result in a greater efflux of H^+ and lactate from active musculature into extracellular compartments, due to a greater intra-extracellular gradient, whilst elevated HCO_3^- can be utilised to buffer against H^+ within extracellular compartments (Bishop, Edge, Davis and Goodman, 2004). The resulting effect is more work completed during exercise of high intensities, which in turn, will improve exercise capacity or performance (Bishop et al., 2004; Marx et al., 2002). It is therefore important to heighten the level of blood alkalosis via changes in pH and HCO_3^- prior to exercise (Gough, Deb, Sparks & McNaughton, 2017a; Jones et al., 2016). Common practice is to prescribe $NaHCO_3$ between a

set time of between 60 and 90 mins for all participants (Carr, Hopkins and Gore, 2011; Price and Singh, 2008; Siegler et al., 2009). In a recent study, however, it was reported time to peak HCO_3^- occurred between 40 and 125 min (Gough et al., 2017a), with a similar variation observed in other dose-response studies (Jones et al., 2016; Miller et al., 2016). Many participants may not therefore achieve peak alkalosis at the start of exercise, which might explain, in part, the lack of an ergogenic effect of $NaHCO_3$ supplemented at 100 min (Correia-Oliveira et al., 2017) and 150 min (Callahan, Parr, Hawley & Burke, 2017) in other 4 km cycling TT studies.

In response to such variation in time to peak alkalosis it is recommended that either time to peak pH or HCO_3^- is predetermined prior to use for an exercise bout, as this accounts for the inter-individual variation commonly observed (McNaughton et al., 2016; Miller et al., 2016; Jones et al., 2016; Gough et al., 2017c). Indeed, preliminary studies to date have displayed ergogenic benefits of $NaHCO_3$ individualised to a predetermined peak pH in cycling performance (Miller et al., 2016; Deb et al., 2017). Gough et al. (2017a) however, recently demonstrated greater reliability of time to peak HCO_3^- compared to time to peak pH with Intraclass Correlation Coefficient (ICC) analysis (r =0.94 vs. 0.71). It may therefore be more appropriate to determine the effects of $NaHCO_3$ on HCO_3^- responses, particularly if the athlete wishes to achieve peak alkalosis consistently. Nonetheless, no study to date has investigated the potential ergogenic effects of $NaHCO_3$ supplementation determined by a predetermined individual time to peak HCO_3^- on an exercise protocol reflective of competitive cycling such as a 4 km TT.

Investigations into the ergogenic effects of individualising $NaHCO_3$ to a predetermined time to peak pH have prescribed an amount of 0.3 $g \cdot kg^{-1}$ BM (Miller et al., 2016; Deb et al., 2017).

51 This is likely due to early research by McNaughton (1992) reporting a dose-dependent effect
52 on performance, with 0.3 $g \cdot kg^{-1}$ BM $NaHCO_3$ improving total work done (TWD) to a greater
53 magnitude than 0.2 $g \cdot kg^{-1}$ during 60 s of maximal cycling; whilst meta-analyses have also
54 shown a meaningful effect on exercise performance following 0.3 $g \cdot kg^{-1}$ BM $NaHCO_3$ (Peart
55 et al., 2012; Carr et al., 2011). Despite this, there is a paucity of literature investigating the
56 dose-dependent ergogenic effects from smaller doses of $NaHCO_3$ on exercise performance.
57 The greater magnitude of effect between 0.3 $g \cdot kg^{-1}$ and 0.2 $g \cdot kg^{-1}$ BM $NaHCO_3$ reported by
58 McNaughton (1992) for instance, was non-significant and only considered one exercise
59 duration/intensity and participant cohort (recreationally active). Furthermore, McKenzie,
60 Coutts, Stirling, Hoeben and Kuzara (1986) reported a negligible 0.3% difference between 0.15
61 $g \cdot kg^{-1}$ BM and 0.3 $g \cdot kg^{-1}$ BM $NaHCO_3$ in a cycling time to volitional exhaustion test at 125%
62 VO_{2max}. Based on such limited evidence, further research is warranted exploring the dose-
63 dependent effects of $NaHCO_3$.
64
65 A further concern of a 0.3 $g \cdot kg^{-1}$ BM $NaHCO_3$ ingestion strategy is the commonly reported
66 gastrointestinal (GI) discomfort symptoms such as stomach cramp, diarrhoea, and in extreme
67 cases, vomiting, which can have major negative implications for exercise performance
68 (Saunders et al., 2014; Gough et al., 2017a, 2017b). It is therefore important to maximise the
69 potential ergogenic effect through attaining peak buffering capacity, whilst also managing the
70 severity of (GI) discomfort. Given that smaller amounts of $NaHCO_3$ (i.e. 0.2 $g \cdot kg^{-1}$ BM) are
71 associated with lower instances and severity of GI discomfort (Gough et al., 2017a, 2017c), it
72 may be prudent to suggest this amount is a better option practically to the athlete aiming to
73 enhance their performance, as long as ergogenic benefits are still evident.
74

To heighten the likeliness of an ergogenic benefit and mitigate the severity of GI discomfort, 0.2 $g \cdot kg^{-1}$ BM $NaHCO_3$ individualised to a predetermined time to peak HCO_3^- may be suitable. Gough et al. (2017a) reported a 5.7 ± 0.9 $mmol \cdot l^{-1}$ increase of HCO_3^- following 0.2 $g \cdot kg^{-1}$ BM $NaHCO_3$ using a time to peak HCO_3^- strategy, which is superior to the 3.9 ± 0.9 $mmol \cdot l^{-1}$ mean change reported in a meta-analysis following a standardised 0.3 $g \cdot kg^{-1}$ BM $NaHCO_3$ dose (Carr et al., 2011). These changes in acid base balance following 0.2 $g \cdot kg^{-1}$ BM $NaHCO_3$ are also close to the 6 $mmol \cdot l^{-1}$ increase purported to lead to an ergogenic effect on performance (Matson & Tran, 1993; Jones et al., 2016). These data combined, suggest 0.2 $g \cdot kg^{-1}$ BM $NaHCO_3$ individualised to a pre-determined time to peak HCO_3^- achieves the required acid base balance changes that may improve performance, whilst also reducing the symptoms of GI discomfort. Despite this, no literature to date has investigated the dose-dependent effects (i.e. 0.2 $g \cdot kg^{-1}$ vs. 0.3 $g \cdot kg^{-1}$ BM $NaHCO_3$) on exercise performance when individualised to a predetermined time to peak HCO_3^-. The purpose of this study, therefore, was to investigate the effects of both 0.2 $g \cdot kg^{-1}$ BM (SBC2) and 0.3 $g \cdot kg^{-1}$ BM (SBC3) $NaHCO_3$ individualised to a predetermined time to peak HCO_3^- on 4 km TT performance. We hypothesised that both SBC2 and SBC3 would reduce the time required to complete the 4 km TT.

Materials and Methods

Participants

A priori power calculation conducted using SPSS Sample Power 3 (IBM, Chicago, IL, USA) displayed a sample size of 11 would allow detection of a 3 s change with high statistical power ($\beta = 0.80$; $0.05 = \alpha$ level). This set criterion was used to detect a difference between $NaHCO_3$ treatments (i.e. SBC2 vs. SBC3) and between SBC treatments and the placebo, as this is the typical difference required to determine medal positions for the men's individual pursuit and similar events at Olympic Games (Christensen et al., 2017). Eleven male trained cyclists

100 therefore volunteered for this study (height 1.82 ± 0.8 m, body mass 86.4 ± 12.9 kg, age 32 ±
101 9 years, peak power output (PPO) 382 ± 22 W) with a weekly training frequency of ≥3 times,
102 for a total of ≥5 hours per week, and for a minimum of 2 years training experience, which was
103 specifically in cycling. Based on these descriptors, participants met the criteria of 'trained
104 cyclist' as described by De Pauw et al. (2013). Participants were also excluded if they had
105 ingested any nutritional buffers (such as beta alanine) in the prior 6 months of the study. Ethical
106 approval was obtained from the Departmental Research Ethics Committee and each participant
107 provided written informed consent prior to experimental testing.
108
109 ***Experimental overview***
110 Participants visited the laboratory on six occasions in a randomised, crossover and double blind
111 designed study (2 x identification of peak blood HCO_3^-, 3 x cycling TT's). Constraints on
112 ingestion of alcohol and participation in any strenuous/unaccustomed exercise were in place
113 24 hours prior to each trial. Caffeine was also prohibited 12 hours prior to any trial. Written
114 logs of nutritional intake were taken, with intake from the first trial replicated for subsequent
115 trials. Participants visited the laboratory in a four-hour postprandial state and trials were
116 conducted at the same time of day to account for circadian rhythms (Reilly, 1990).
117 Experimental trials were separated by at least three days to allow acid base balance variables
118 to return to normal resting concentrations (Siegler et al., 2009).
119
120 ***Identification of time to peak blood bicarbonate***
121 On two separate occasions participants ingested either 0.2 $g \cdot kg^{-1}$ BM $NaHCO_3$ (SBC2) or 0.3
122 $g \cdot kg^{-1}$ BM $NaHCO_3$ (SBC3) mixed with 400 ml of water and 50 ml double strength and sugar-
123 free blackcurrant cordial to identify time to peak blood HCO_3^- and pH. Whilst quietly resting
124 and seated, finger prick capillary blood samples were collected in a 100µl sodium heparin-

125 coated glass clinitube every 10 min for analysis of blood HCO_3^- and pH over a 120 min period
126 using a blood gas analyser (ABL800 BASIC, Radiometer Medical Ltd. Denmark). The highest
127 HCO_3^- value was used as a determination of time to peak HCO_3^- and this determined the timing
128 of ingestion for experimental trials. Supplementation of $NaHCO_3$ was double blinded and
129 randomised (block randomisation), as a laboratory technician outside of the research group
130 prepared the $NaHCO_3$. Likewise, the time to peak HCO_3^- was determined by researchers
131 outside of the study and the participant was not informed of their time to peak to ensure the
132 double blind nature of the study. For the PLA condition, a time to peak HCO_3^- was used from
133 either SBC2 or SBC3.
134
135 ***Four-kilometre cycling protocol, blood measures and perceptual measures***
136 The next visit involved a familiarisation to the 4 km cycling TT on a Velotron cycle ergometer
137 (Velotron, RacerMate Inc., USA) interfaced with Velotron coaching software (RacerMate Inc.,
138 USA). This ergometer has displayed high test-retest reliability with excellent ICC values of
139 between r =0.90 to 0.96, p <0.01 for mean power in TT events (Astorino, 2011; Costa,
140 Guglielmo & Paton, 2017). Participants selected a preferred handlebar and saddle position,
141 whilst they were also permitted to change gears freely throughout each TT using their preferred
142 fixed gear ratios. These settings were then adopted for all subsequent trials. Strong verbal
143 encouragement was provided throughout the TT and feedback on the distance covered and
144 cadence was provided via the software (Stone et al., 2011), but time elapsed was blinded. Time
145 to complete, mean power and mean speed was recorded for both the total distance and 0.5 km
146 splits, along with heart rate (HR) every 0.5 km (Polar, T31, Finland). Blood measures for pH
147 and HCO_3^- were taken pre-ingestion and post-exercise as per the previously described method.
148 A 5µl sample for blood lactate (BLa) was also taken at the same respective time points (Lactate
149 Pro 2, Arkray, Japan). Ratings of perceived exertion (6-20; Borg, 1982) for the whole body

150 (RPE_O), legs (RPE_L), and affective perceptions of work rate (11-point bipolar scale with +5
151 representing 'very good' and -5 representing 'very bad') were recorded every 1 km (Thomas
152 et al., 2015). This procedure was repeated another three times, with the exception that either
153 0.2 $g \cdot kg^{-1}$ BM $NaHCO_3$ (SBC2), 0.3 $g \cdot kg^{-1}$ BM $NaHCO_3$ (SBC3) or a taste matched placebo
154 (PLA) containing 0.07 $g.kg^{-1}$ BM sodium chloride (NaCl) was ingested, after baseline measures
155 were taken. Participants then sat quietly rested until their respective predetermined time to peak
156 HCO_3^-, at which point a further blood sample was taken. Treatments were administered in a
157 double-blind manner, and for PLA treatments, a time to peak HCO_3^- time frame from an SBC
158 treatment was selected randomly by a researcher outside of the study to maintain the double-
159 blind design. Following ingestion, and up to the individuals respective time to peak HCO_3^-, GI
160 discomfort was measured using a visual analogue scale (VAS) every 10 min, as per previous
161 studies (Miller et al., 2016; Gough et al., 2017a).
162
163 **Statistical analysis**
164 Assessed variables were analysed using both Shapiro-Wilk tests and standard graphical
165 methods for normality, whilst a Mauchly test was used for homogeneity and
166 variance/sphericity. A paired sampled t-test was used to assess the severity and time to peak
167 GI discomfort between SBC treatments. Both mean power and speed were analysed using a
168 repeated measures ANOVA. Otherwise, a two-way repeated measures ANOVA (e.g. condition
169 x each 0.5 km segment/time point) was used and where either interactions or main effects were
170 observed, Bonferroni corrected posthoc pairwise comparisons were carried out. Where main
171 effects or interactions were observed, partial eta squared ($P\eta^2$) effect size is reported. Between
172 treatment effect sizes (d) were calculated using the difference in means divided by the pooled
173 SD of the compared trials (Nagakawa & Cuthill, 2007), however with a Hedge's g bias
174 correction to account for the sample size in this study (Lakens, 2013). All effect size

interpretations were considered as trivial (<0.20), small (0.20-0.49), moderate (0.50-0.79) or large (≥0.80) (Cohen, 1988). Intraclass Correlation Coefficients (ICC) were used to determine the reproducibility of blood metabolites (i.e. time to peak HCO_3^- and pH) following SBC conditions and are reported with *r* value and significance value (p value). Interpretation of reproducibility was determined by the respective *r* value with categories of poor (<0.40), fair (0.40-0.59), good (0.60-0.74) and excellent (>0.74). Data are presented as mean ± SD with 95% confidence intervals (CI) unless otherwise stated. Statistical significance was set at p <0.05 and data were analysed using SPSS v22 for Windows (SPSS Inc., Chicago, IL, USA).

Results

Performance responses for all participants (n =11)

Faster mean completion times (Figure 1) by 8.3 ± 3.4 s were observed following SBC2 (p < 0.001, CI = 12.0, 4.7, *d* = 0.64) and by 8.6 s ± 5.2 s following SBC3 compared to PLA, respectively (p =0.003, CI = 14.2, 3.0, *d* =0.66). There was no difference between SBC2 and SBC3 (374.0 ± 13.3 vs. 373.7 ± 13.3 s, p =0.87, CI = -3.0, 3.7, *d* =0.02; Figure 1).

Figure 1 near here

A 16 ± 13 W (+5.7%) increase in mean power was observed following SBC2 (304 ± 28 W, p =0.02, CI = 2.6, 30.3, *d* =0.62), while in SBC3 an increase of 16 ± 15 W (+5.9%) was observed (304 ± 31 W, p =0.03, CI = 1.1, 32.9, *d* =0.58; Figure 2a) compared to PLA (287 ± 25 W). There was no difference between SBC2 and SBC3 (p =0.90, CI = -10.2, 9.1, *d* =0.01). Following SBC2, a 0.9 ± 0.6 $km.h^{-1}$ (+2.4%) increase in mean speed was observed compared to PLA (38.6 ± 1.4 vs. 37.7 ± 1.1 $km.h^{-1}$, p =0.008, CI = 0.2, 1.6, *d* =0.69). Similarly, a 0.8 ± 0.6 $km.h^{-1}$ (+2.0%) increase in mean speed was observed following SBC3 (38.4 ± 1.3, p =0.02,

CI = 0.1, 1.4, *d* =0.56), whilst there was no difference between SBC conditions (p =0.42, CI = -0.3, 0.6, *d* =0.14; Figure 2b).

** Figure 2 near here**

Performance responses for participants who suffered gastrointestinal (GI) discomfort (n =8)

Despite the occurrence of GI discomfort, SBC2 improved performance by 9.0 ± 3.8 s in SBC2 (p =0.001, CI = 4.5, 13.5, *d* = 0.68) and 8.9 ± 6.1 s in SBC3 (p =0.02, CI = 1.7, 16.2, *d* = 0.68) compared to PLA. Only one participant failed to improve performance (0.1 s difference vs. PLA), whilst three participants improved by less than the 3 s threshold that was set in the priory power calculation for a meaningful effect (range = 2-2.6 s improvement vs. PLA).

Blood metabolite responses

Absolute peak change in HCO_3^- from baseline was 5.5 ± 0.7 in SBC2 and 6.5 ± 1.3 $mmol \cdot l^{-1}$ in SBC3 which was not significantly different (p =0.07; *d* =0.92). Peak HCO_3^- occurred within a range of between 40 to 110 mins in SBC2 (mean 62 ± 20 min, CV: 33%), and between 40 to 100 min in SBC3 (mean 73 ± 20 min, CV: 27%; Figure 3).

Figure 3 near here

The change from baseline to the peak pH was not significantly different between SBC conditions (p =0.13, *d* =0.75; SBC2 =0.07 ± 0.02, SBC3 =0.09 ± 0.03). In subsequent cycling trials (i.e. 4km TT's) good reproducibility was observed for absolute mean change from baseline in pH following both SBC2 (+0.06; ICC *r* =0.67, p =0.026) and SBC3 (+0.06; *r* =0.65, p =0.040). Greater reproducibility was observed for absolute mean change in HCO_3^- however,

displaying excellent reliability in both SBC2 (+4.9 mmol·l^{-1}; r =0.86, p =0.002) and SBC3 (+5.6 mmol·l^{-1}; r =0.88, p <0.001).

In the cycling trials, a time × treatment interaction was observed for pH (p =0.048, $P\eta^2$ =0.285) whereby pH was +0.07 ± 0.02 (+0.9%) greater at time to peak (figure 4a) for SBC2 (7.46 ± 0.03; p <0.001, CI = 0.09, 0.04, d =2.64) and 0.08 ± 0.02 (+1%) greater for SBC3 (7.47 ± 0.02; p <0.001, CI = 0.09, 0.05, d =3.85) compared to PLA (7.39 ± 0.02). There was no difference between SBC2 and SBC3 (p =0.69, CI = -0.3, 0.1; d =0.38). A time × treatment interaction was observed for HCO_3^- (p <0.001, $P\eta^2$ =0.796), with values greater following supplementation of $NaHCO_3$ (Figure 4b). At time to peak HCO_3^-, SBC2 was 5.0 mmol·l^{-1} ± 1.0 mmol·l^{-1} (+17.6%) (28.6 ± 1.1 mmol·l^{-1}; p <0.001, CI = 6.0, 4.1, d =5.22) and SBC3 was 5.9 ± 1.1 mmol·l^{-1} (+20.0%) (29.5 ± 1.0 mmol·l^{-1}; p <0.001, CI = 6.9, 5.0, d =6.58) greater than PLA (23.6 ± 0.7 mmol·l^{-1}). There was no difference between SBC2 and SBC3 (p =0.34, CI = -2.3, 0.6, d =0.82).

Post exercise HCO_3^- was +1.8 ± 1.3 mmol·l^{-1} (+12.3%) greater for SBC2 (16.0 ± 2.2 mmol·l^{-1}; p =0.004, CI = 2.9, 0.6, d =0.79), and +1.5 ± 1.3 mmol·l^{-1} (+10.9%) greater for SBC3 (15.8 ± 2.7 mmol·l^{-1}; p =0.01, CI = 2.7, 0.4, d =0.62) compared to PLA (14.2 ± 2.2 mmol·l^{-1}). There was a main effect for treatment in HCO_3^- change during exercise (p <0.001, $P\eta^2$ =0.714), whereby the change in HCO_3^- was 3.3 ± 1.8 mmol·l^{-1} (+25.9%) greater following SBC2 (12.7 ± 2.6 mmol·l^{-1}; p =0.001, CI = 4.9, 1.6, d =1.37) and 4.4 ± 1.7 mmol·l^{-1} (+31.7%) greater for SBC3 (13.8 ± 2.7 mmol·l^{-1}; p <0.001, CI = 5.9, 2.8, d =1.78) compared to PLA (9.4 ± 2.0 mmol·l^{-1}). There was no difference between SBC conditions (p =0.59, CI = -1.2, 3.3; d =0.40). A main effect for time was observed for BLa (p <0.001, $P\eta^2$ =0.957) with all conditions displaying greater post-exercise BLa compared to pre-exercise (Figure 4c). Post-exercise, a time × treatment interaction was observed for BLa (p <0.001, $P\eta^2$ =0.577) as SBC2 was +3.7

± 2.8 mmol·l^{-1} (+22.5%) greater than PLA (16.1 ± 3.4 vs. 12.5 ± 2.7 mmol·l^{-1}, p =0.006, CI = 1.1, 5.8, *d* =1.13; Figure 4c), with SBC3 greater by +3.7 ± 2.4 mmol·l^{-1} (+22.7%) (16.1 ± 3.4 mmol·l^{-1}; p =0.002, CI = 1.5, 5.8, *d* =1.13). No differences between SBC conditions were evident for post-exercise BLa (p =0.61, CI = -2.3, 2.2; *d* =0.01).

*Figure 4 near here**

Gastrointestinal (GI) discomfort

Four participants reported symptoms of belching and stomach bloating in SBC2, compared to seven participants reporting symptoms of belching, stomach cramp, bowel urgency and diarrhoea in SBC3. There was no significant difference in severity of GI discomfort between SBC treatments (SBC2 =1.4 ± 1.5 vs. SBC3 =4.6 ± 3.6; p =0.10), although a large effect size was evident (*d* =0.88). Similarly, time to peak GI discomfort was not significantly different between SBC treatments (SBC2 =20 ± 24 vs. SBC =43 ± 31min, p =0.13), although revealed a large effect size (*d* =0.80).

Heart rate (HR), ratings of perceived exertion (RPE) and affective perceptions of work rate scale

Heart rate was unaffected by $NaHCO_3$ ingestion as no time × treatment interaction was observed (p =0.56, $P\eta^2$ =0.055). There was a main effect for time (p <0.001, $P\eta^2$ =0.977) for HR and mean data combined from all treatments displayed HR at 500m was 144 ± 3 b·min^{-1}, compared to 171 ± 2 b·min^{-1} at 4 km, respectively. A main effect for time was observed for RPE_O (p <0.001, $P\eta^2$ =0.849), as at 1 km RPE_O was 14 ± 1 compared to 17 ± 1 at 4 km, although no time × treatment was apparent (p =0.31, $P\eta^2$ =0.109). A main effect for time was observed for RPE_L (p <0.001, $P\eta^2$ =0.657), as at 1 km RPE_L was 15 ± 1 compared to 18 ± 0 at 4 km,

275 although no time × treatment interaction was evident (p =0.73, $P\eta^2$ =0.085). Affective
276 perceptions of work rate revealed no time × treatment interaction (p =0.38, $P\eta^2$ =0.099) or main
277 effect for time (p =0.92, $P\eta^2$ =0.020).
278
279 **Discussion**
280 In agreement with our hypothesis, this study reports that both 0.2 g·kg^{-1} (SBC2) and 0.3 g·kg^{-1}
281 BM (SBC3) $NaHCO_3$ improves 4 km TT cycling performance in trained cyclists when
282 individualised to a predetermined time to peak HCO_3^-. Time to complete the time trial was
283 2.2% faster in SBC2 and 2.3% in SBC3 compared to PLA, whilst there was also no statistical
284 difference between SBC conditions suggesting both amounts are appropriate to enhance this
285 type of exercise performance. Combining such performance effects with the reduced instances
286 and severity of GI discomfort following 0.2 g·kg^{-1} BM $NaHCO_3$ however, the present study
287 findings suggest this amount may be more attractive to the athlete in a practical setting.
288
289 The findings of the present study contrast that of two recent studies reporting no effect of
290 $NaHCO_3$ on 4 km TT performance (Callahan et al., 2017; Correia-Oliveira et al., 2017). Indeed,
291 Callahan et al. (2017) reported a '*possibly trivial*' effect and Correia-Oliveira (2017) reported
292 no significant supplement interaction in ANOVA analysis following 0.3 g·kg^{-1} BM $NaHCO_3$.
293 In comparison, the present study displayed a statistically significant effect and a moderate
294 effect size for both SBC2 and SBC3. This ergogenic effect was most likely realised due to
295 supplementing $NaHCO_3$ to a predetermined time to peak HCO_3^-, as this would have ensured
296 peak bioavailability of HCO_3^- at the commencement of exercise. In particular, the increase in
297 HCO_3^- following the SBC2 treatment of the present study was similar, whilst the SBC3
298 treatment was superior, to the values reported in the aforementioned studies with 0.3 g·kg^{-1} BM
299 $NaHCO_3$ (SBC2 = 4.9 to 5.5 mmol·l^{-1}, SBC3 = 5.6 to 6.5 mmol·l^{-1} vs. Callaghan et al. = +3

300 mmol·l^{-1} vs. Correia-Oliveira et al. = +5mmol·l^{-1}). Based on this evidence, it is therefore more
301 appropriate to identify time to peak HCO_3^- prior to the use in exercise to elicit ergogenic effects
302 on performance. A consideration, however, is that identifying time to peak HCO_3^- presents a
303 logistical challenge, as this would require a visit to a laboratory or access to a portable blood
304 gas analyser.
305
306 A unique finding of the present study was the lack of a dose-dependent effect on exercise
307 performance, with SBC3 improving performance to a similar magnitude as SBC2. These
308 findings are in contrast to McNaughton (1992), reporting 0.3 g·kg^{-1} BM $NaHCO_3$ improved
309 TWD greater than 0.2 g·kg^{-1} BM $NaHCO_3$ during 60 seconds of maximal cycling compared to
310 a placebo. The negligible 0.1% difference observed between SBC2 and SBC3 are more in
311 agreement with the findings of McKenzie et al. (1986) reporting a 0.3% difference between
312 0.15 g·kg^{-1} BM and 0.3 g·kg^{-1} BM $NaHCO_3$. Individual performance responses did reveal that
313 three participants improved to a greater extent in SBC2 compared to SBC3, whilst two
314 participants improved to a greater extent in SBC3 compared to SBC2 based on the 3 s cut off
315 from the prior power calculation. These data combined suggest lower amounts of $NaHCO_3$ (i.e.
316 0.2 g·kg^{-1} BM) are likely to be sufficient to enhance exercise of this duration and intensity,
317 although athletes should trial each dose prior to use in competition to evaluate which amount
318 of $NaHCO_3$ provides a larger ergogenic benefit. Likewise, considering the potential for the
319 onset of GI discomfort, athletes who are susceptible to such symptoms should conduct a
320 risk:benefit analysis of $NaHCO_3$ supplementation.
321
322 It is purported that mitigating the severity of GI discomfort is important to obtain a performance
323 benefit following $NaHCO_3$ supplementation, as Saunders et al. (2014) reported a significant
324 effect on performance only upon the removal of participants who suffered from GI discomfort.

The present study findings contrast this by reporting a significant 2.3% improvement following both SBC2 and SBC3, despite the occurrence of mild to moderate GI discomfort. Reasons for this may be due to the good tolerance of $NaHCO_3$ in our participant cohort, although it is difficult to compare with the work of Saunders et al. (2014) as no explicit statistical analysis on GI discomfort is available. Nonetheless, there may still be a relationship between GI discomfort and performance, as for instance, participant 8 in the present study suffered from moderate diarrhoea and bowel urgency in SBC3 and no improvement in performance was observed (0.1 s). While performance in SBC2 was improved by 8.9 s in the same participant when no instances of GI discomfort occurred. Combining this finding with other investigations where participants have self-withdrawn, or have been withdrawn by the research team due to the severity of GI discomfort, the responses from $NaHCO_3$ still warrant observation in training prior to use in competition (Gough et al., 2017a, 2017b; Jones et al., 2016). Nonetheless, smaller amounts of $NaHCO_3$ may be an attractive solution to the athlete to reduce the severity of GI discomfort symptoms whilst still providing ergogenic effects to exercise performance.

The enhancements of acid base balance following $NaHCO_3$ are the most likely mechanism for an improved performance in the present study, as both SBC2 and SBC3 raised HCO_3^- and pH significantly compared PLA. An increase in extracellular HCO_3^- is suggested to increase H^+ efflux during exercise due to the up-regulation of the lactate/H^+ cotransporter, leading to increased provision of anaerobic energy contribution (Marx et al., 2002). The change in HCO_3^- was superior in both SBC2 (+25.9% vs. PLA) and SBC3 (+31.7% vs. PLA) whilst post-exercise blood lactate was also significantly higher (~15%) in the SBC conditions. These changes in blood acid base balance and BLa are indicative of exercise at higher exercise intensities in the SBC conditions and hence, improved performance. Furthermore, between SBC conditions there were minimal differences in respect of blood metabolites changes prior

to, or during exercise. This provides an explanation why there were no dose-dependent effects on performance in the present study.

Conclusion

Ingestion of $NaHCO_3$ individualised to time to peak HCO_3^- improves 4 km TT cycling performance in trained cyclists. Ingestion of both 0.2 $g \cdot kg^{-1}$ BM and 0.3 $g \cdot kg^{-1}$ BM $NaHCO_3$ equally increase buffering capacity and subsequently provided ergogenic benefits to exercise performance. No difference was observed between SBC conditions; therefore, athletes can plausibly use a lower amount of $NaHCO_3$ (i.e. 0.2 $g \cdot kg^{-1}$ BM) particularly if they are susceptible to the onset GI discomfort. Future research should investigate the dose-dependent effects of both 0.2 $g \cdot kg^{-1}$ BM and 0.3 $g \cdot kg^{-1}$ BM $NaHCO_3$ during exercise of different intensities and durations.

Disclosure statement

The authors report no conflicts of interest.

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List of figures