Effect of warm up and sodium bicarbonate ingestion on 4-km cycling time trial performance

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Abstract

Purpose: This study examined whether an ecologically valid, intermittent, sprint-based warm up strategy impacted the ergogenic capacity of individualised sodium bicarbonate ($NaHCO_3$) ingestion on 4-km cycling time trial (TT) performance. **Methods:** Eight male cyclists attended six laboratory visits for familiarisation, determination of time to peak blood bicarbonate (HCO_3^-) and 4x4-km cycling TT's. Experimental beverages were administered double-blind. Treatments were conducted in a block randomized, crossover order: intermittent warm up + $NaHCO_3$ (IWSB), intermittent warm up + placebo (IWP), control warm up + $NaHCO_3$ (CWSB), control warm up + placebo (CWP). The intermittent warm up comprised exercise corresponding to lactate threshold (5 min at 50%; 2 min at 60%; 2 min at 80%; 1 min at 100%; 2 min at 50%) and 3x10s maximal sprints. The control warm up comprised 16.5 min cycling at 150W. Participants ingested 0.3 $g.kg^{-1}$ BM $NaHCO_3$ or 0.03 $g.kg^{-1}$ BM sodium chloride (placebo) in 5 $ml.kg^{-1}$ BM fluid (3:2, water and sugar-free orange squash). Paired *t* tests were conducted for TT performance. Haematological data (HCO_3^-; lactate, BLa^-) and gastrointestinal discomfort were analysed using repeated measures ANOVA. **Results:** Performance was faster for CWSB vs. IWSB (5.0±6.1s; p=0.052) and CWP (5.8±6.0s; p=0.03). Pre-TT [HCO_3^-] was elevated for CWSB vs. IWSB (+9.3$mmol.l^{-1}$; p<0.001) and CWP (+7.1$mmol.l^{-1}$; p<0.001). Post-TT [BLa^-] was elevated for CWSB vs. CWP (+2.52$mmol.l^{-1}$; p=0.022). Belching was exacerbated pre-warm up for IWSB vs. IWP (p=0.046) and CWP (p=0.027). **Conclusion**: An intermittent, sprint-based warm up mitigated the ergogenic benefits of $NaHCO_3$ ingestion on 4-km cycling TT performance.

Keywords: buffering, alkalosis, metabolic perturbation, sprints, ergogenic aid.

Introduction

Competitive cycling time trial (TT) events such as the individual pursuit require athletes to almost maximally exert themselves for short durations (~5 min). The substantial anaerobic energy demand results in the accumulation of metabolites including inorganic phosphate, hydrogen ions (H^+), and lactate.[1] Extracellular buffering mechanisms act to remove these H^+ from the skeletal muscle cell, but once production rates overwhelm neutralization reactions, the excess H^+ contribute towards decreasing intramuscular pH.[2] Exercise-induced acidosis inhibits glycolytic energy production and disturbs calcium ion cross-bridge formation,[1,3] which may accelerate the development of peripheral fatigue during high-intensity exercise.[1] Strategies that protect against these biochemical disturbances could therefore be vital to optimising exercise performance.

Various extracellular buffering agents exist that elicit a metabolic alkalosis which improves the capacity to buffer H^+ during high-intensity exercise. Perhaps the most well-established and extensively researched is sodium bicarbonate ($NaHCO_3$).[4] This nutritional supplement enhances the extracellular buffering response by elevating circulating blood bicarbonate (HCO_3^-) ~5-6 $mmol.l^{-1}$ above baseline,[4] which promotes greater efflux of H^+ from the muscle, in turn protecting against declining intramuscular pH.[5] $NaHCO_3$ ingestion also elevates strong ion difference (SID) by ~15%,[6,7] subsequently allowing for sustained muscle excitability during strenuous exercise.[1] Since there is no singular explanation for performance enhancing effects,[5] authors should adopt a multifaceted perspective when examining physiological mechanisms associated with $NaHCO_3$ ingestion.

$NaHCO_3$ has historically been administered as a 0.3 $g.kg^{-1}$ BM dose at 60-90 min pre-exercise, which may elicit moderate improvements to high-intensity exercise performance.[4] Some authors have reported no effect (≤0.5%) of $NaHCO_3$ on 4-km cycling TT performance,[8,9] although this was attributed to their failure to account for inter-individual variability in HCO_3^- absorption rates. Athletes are recommended to align $NaHCO_3$ timing with individualised time to peak HCO_3^- kinetics, ensuring that peak changes in HCO_3^- occur immediately pre-exercise,[10,11] thus maximising HCO_3^- buffering capacity. Individualised $NaHCO_3$ ingestion has previously increased work during repeated sprints (+10.7%)[11] and improved 4-km TT completion times (~8 s).[10,12] Considering that time to peak HCO_3^- varies considerably between athletes, ranging from 40-120 min depending on administration method (solution vs. capsule),[10,13] research should opt for individualised $NaHCO_3$ ingestion to maximise ergogenic potential.

Most studies examining the effect of $NaHCO_3$ on high-intensity cycling performance provided participants with steady state warm ups[9-12] that are unlikely to have replicated metabolic perturbation experienced during warm up strategies preceding competition. Kilding et al[14] suggested that an intermittent cycling warm up (20 min at 60-65% maximal aerobic power, 5x20 s sprints) decreased HCO_3^- by ~5 $mmol.l^{-1}$ from baseline in the placebo trial, with only a small increase (+3.7 $mmol.l^{-1}$) reported pre-TT after $NaHCO_3$ ingestion. Other authors employing sport specific warm up strategies observed no effect of $NaHCO_3$ on sprint time during water polo (+0.4%; p=0.51) and rugby (p>0.05) tests.[15,16] As these studies failed to examine differences in acid-base balance between pre- to post-warm up, it is difficult to determine the extent to which warm up strategy impacted upon HCO_3^- response, or may have altered ergogenic capacity. Further investigation is warranted to compare the effect of different warm up strategies on changes in acid-base balance and performance benefits.

Elite cyclists complete intermittent warm ups, including bouts of sustained high-intensity and maximal sprints.[17] These exercise bouts result in the accumulation of H^+ within the muscle,[1,3] potentially utilising the enhanced buffering response prior to competition. To date, no research has investigated whether these metabolic perturbations negatively impact the efficacy of $NaHCO_3$ ingestion. Therefore, the aim of this study was to examine the effect of an

ecologically valid, intermittent, sprint-based warm up and individualised $NaHCO_3$ ingestion on 4-km cycling TT performance in cyclists.

Methods

Participants

Ten club-level male cyclists (1.82±0.5 m; 73.3±6.6 kg; 54.8±5.1 ml.kg.min^{-1}; 23±7 years) volunteered for this study (due to global pandemic only 8 completed). All participants were categorised as either recreationally trained or trained cyclists[18] and performed >4 h of cycling-based training per week, had cycled for >2 years and had not ingested buffering agents in the previous 6 months. Ethical approval was gained from the Human Ethics Committee at Nottingham Trent University. Participants signed informed consent prior to data collection, with research conducted in accordance to the Revised Helsinki Declaration (2013).

Experimental Design

A block randomized, double-blind, placebo-controlled, crossover experimental design was employed for this study. Participants attended six separate laboratory visits to perform a graded exercise test and protocol familiarisation, determination of time to peak HCO_3^- and 4x4-km cycling TT's. Participants performed testing at the same time of day (±2 h) and in a 2 h postprandial state to minimise the confounding effects of circadian rhythms[19] and nutrition on exercise performance. Vigorous exercise and the consumption of alcohol were prohibited for 24 h prior to all visits. Pre-trial nutrition and exercise were replicated for 24 h prior to experimental trials (checked via visual logs). Participants completed profile of mood states[20] and Pittsburgh sleep quality[21] questionnaires to calculate total mood disturbance (TMD) and global sleep quality index (GSQI).

Graded Exercise Test and Familiarisation

Participants completed a graded exercise test on their own bike mounted to an online cycling system (Cyclus2, RBM elektronik-automation GmbH, Germany). Baseline capillary blood samples were collected into 20µl sodium heparised capillary tubes and analysed for blood lactate (BLa^-) using the Biosen C-Line (EKF Diagnostic GmbH, Germany). The protocol commenced at 95W and increased by 35W every 3 min. Heart rate and blood samples were taken at the end of each stage until [BLa^-] exceeded 4.0 mmol.l^{-1}, at which point only heart rate was recorded until volitional exhaustion. This was classified by the failure to maintain self-selected cadence (80±7 rev.min^{-1}) despite strong verbal encouragement. Gaseous exchange was collected throughout using a breath-by-breath metabolic analyser (Vyntus CPX, CareFusion GmbH, Germany). The power output at lactate threshold (LT; 4.0 mmol.l^{-1}) was used to prescribe the intermittent warm up strategy.

Participants were familiarised to exercise protocols, with 10 min complete rest seated on a chair between the intermittent warm up and 4-km cycling TT. This reflects real life time lapse in elite competition (personal experience of S.Faulkner). The intermittent warm up comprised exercise corresponding to LT (5 min at 50%, 2 min at 60%, 2 min at 80%, 1 min at 100%, 2 min at 50%) and 3x10 s maximal sprints interspersed with 90 s recovery. All exercise was completed on the participants' own bike. Participants selected frame geometry and gear ratios, which were replicated during experimental trials. Participants were provided with feedback on distance covered and cadence, but elapsed time was blinded.

Determination of Time to Peak Blood Bicarbonate

The second laboratory visit was conducted to identify time to peak HCO_3^- following the ingestion of 0.3 g.kg^{-1} BM $NaHCO_3$. Beverages were administered in 5 ml.kg^{-1} BM fluid (3:2, water and sugar-free, orange squash) and consumed within 5 min. Capillary blood samples

were taken prior to $NaHCO_3$ ingestion and collected into 70µl heparin-coated capillary tubes for analysis of HCO_3^- using a blood gas analyser (ABL90 FLEX, Radiometer Medical Ltd., Denmark). Blood samples were taken every 20 min until 60 min post-ingestion, and every 10 min between 60 and 120 min to determine time to peak HCO_3^-.

Experimental Trials

Participants attended four laboratory visits performing the intermittent or a control warm up prior to 4-km cycling TT's. The control warm up comprised cycling at 150W for 16.5 min (matched duration to intermittent warm up). $NaHCO_3$ or 0.03 $g.kg^{-1}$ sodium chloride (placebo) were administered double-blind in 5 $ml.kg^{-1}$ BM fluid (3:2, water and sugar-free, orange squash). Experimental trials were conducted in a randomised order: intermittent warm up + $NaHCO_3$ (IWSB), intermittent warm up + placebo (IWP), control warm up + $NaHCO_3$ (CWSB), control warm up + placebo (CWP). Supplement belief questionnaires were completed post-ingestion to assess perception of experimental beverages.[10,22] Capillary blood samples were taken at baseline, pre-warm up, pre-TT, post-TT and 5 min post for the analysis of HCO_3^-, pH, BLa^-, and electrolytes including sodium (Na^+), potassium (K^+), chloride (Cl^-) and calcium (Ca^{2+}). These were inputted into a freely available spreadsheet to calculate apparent SID: $[K^+] + [Na^+] + [Ca^{2+}] + [Mg^{2+}] - [Cl^-] - [BLa^-]$.[23] Visual analogue scales (0 mm = "no symptom"; 100 mm = "severest symptom") were completed at baseline, pre-warm up, pre-TT and post-TT to measure gastrointestinal (GI) discomfort.[22] The start time of the warm up varied to ensure TT's commenced at the point coinciding with time to peak HCO_3^-. Participants were instructed to complete each 4-km TT as fast as possible.

Statistical Analysis

Normality and sphericity were assessed using Shapiro-Wilk and Mauchly tests, respectively. Reproducibility of pre-trial nutrition, TMD and GSQI were categorised using intraclass correlation coefficients as poor ($r \leq 0.40$), fair ($r = 0.40$-0.59), good ($r = 0.60$-0.74) or excellent ($r \geq 0.74$).[24] Paired *t* tests were conducted on TT performance to assess the effect of $NaHCO_3$ (CWSB vs. CWP), the effect of intermittent warm up (CWSB vs. IWSB), and the combined effects (ΔCWSB/CWP vs. ΔIWSB/IWP). This statistical approach was considered more appropriate than one-way repeated measures ANOVA due to our a priori hypothesis (i.e. no interest in comparing IWSB vs. CWP or IWP vs. CWSB). Bonferroni corrections were performed to minimise the risk of bias due to type I error following multiple tests.[25] The smallest worthwhile change in 4-km TT performance (4.4 s) was calculated as 0.3 x the inter-individual SD for 4-km TT completion time during familiarisation.[26] Between treatment effect sizes were calculated by dividing mean differences by pooled SD, before applying Hedges g bias correction.[27] These were interpreted as trivial (<0.20), small (0.20–0.49), moderate (0.50–0.79), or large (≥0.80). Haematological data were analysed using two-way (treatment x time) repeated measures ANOVA. Significant interactions were explored by performing one-way repeated measures ANOVA across treatments at each time point, with bonferroni correction factors applied. Friedman's two-way ANOVA were conducted for GI discomfort data. Post-hoc Wilcoxon matched-pair signed rank tests were performed when significance was observed, with median and *Z* score reported. Data are presented as mean±SD and 95% confidence intervals (CI) reported for differences in performance. Statistical significance was set at $p<0.05$ (adjusted to $p<0.017$ for TT performance following Bonferroni correction) and data analysed using SPSS v26 (SPSS Inc., IBM, USA).

Results

Pre-experimental Phase

Nutritional intake prior to experimental trials displayed excellent reproducibility for calories (r=0.94; p<0.001), carbohydrate (r=0.94; p<0.001), fat (r=0.96; p<0.001) and protein (r=0.98; p<0.001). Excellent reproducibility was reported for TMD (r=0.94; p<0.001) and GSQI (r=0.95 p<0.001) across experimental trials.

Time Trial Performance

Mean and inter-individual variation for 4-km TT completion times are displayed in **Figure 1**. Completion time was 5.8 s faster for CSWB vs. CWP (CI: 0.7, 10.8; p=0.03) and displayed a large effect size (g=0.89). Completion time was 5.0 s faster for CWSB vs. IWSB (CI: 0.7, 10.1; p=0.052) and displayed a moderate effect size (g=0.76). Six participants reported their fastest 4-km completion time for CWSB. Four participants improved above the smallest worthwhile change (>4.4 s) for CWSB compared to both CWP and IWSB. A small effect size was displayed for 4-km completion time for ΔCWSB/CWP vs. ΔIWSB/IWP (-4.9 s; g=0.42; p=0.233). Large effect sizes were reported for completion time during the first km segment for CWSB vs. CWP (-2.2 s; g=0.92; p=0.025), during the second km segment for CWSB vs. IWSB (-1.5 s; g=0.81; p=0.042) and during the final km segment for CWSB vs. IWSB (-1.9 s; g=1.03; p=0.018).

[INSERT **Figure 1** NEAR HERE]

Average power across the 4-km distance increased +9.9W for CWSB vs. CWP (CI: 0.1, 19.8; p=0.049) and displayed a moderate effect size (g=0.77). Average power across the 4-km distance increased +10.7W for CWSB vs. IWSB (CI: 2.7, 18.6; p=0.016) and displayed a large effect size (g=1.04). Six participants reported their greatest average power for CWSB. A small effect size was displayed for average power across the 4-km distance for ΔCWSB/CWP vs. ΔIWSB/IWP (+11.5W; g=0.47; p=0.192). Moderate effect sizes were reported for average power for CWSB vs. IWSB during the second km (+9.7W*;* g=0.79; p=0.046) and the third km segments (+16.8W; g=0.70; p=0.029). The pacing per km data for average power during the 4-km TT's are displayed in **Figure 2**.

[INSERT **Figure 2** NEAR HERE]

Haematological Data

Significant treatment x time interactions were observed for [HCO_3^-] (p<0.001; η_p^2=0.877) and blood pH (p<0.001; η_p^2=0.774). Pre-warm up [HCO_3^-] and blood pH were elevated for $NaHCO_3$ vs. placebo conditions (~6.2 mmol.l^{-1}; ~0.060 AU). Participants only entered the TT in an alkalotic state following CWSB with pre-TT [HCO_3^-] and blood pH greater for CWSB vs. IWSB (+9.3 mmol.l^{-1}; +0.060 AU), IWP (+15.3 mmol.l^{-1}; +0.064 AU) and CWP (+7.1 mmol.l^{-1}; +0.056 AU). Absolute decline in [HCO_3^-] and blood pH during the TT were greater for CWSB vs. IWSB (-9.6 mmol.l^{-1}; -0.108 AU). Post-TT [HCO_3^-] and blood pH were elevated for $NaHCO_3$ vs. placebo conditions (~2.9 mmol.l^{-1}; ~0.067 AU). At 5 min post [HCO_3^-] and blood pH were elevated for $NaHCO_3$ vs. placebo conditions (~3.3 mmol.l^{-1}; ~0.078 AU). Mean±SD for [HCO_3^-] and blood pH response are displayed in **Figure 3 (A-B)**.

[INSERT **Figure 3 (A-B)** NEAR HERE]

Significant treatment x time interactions were observed for [BLa^-] (p<0.001; η_p^2=0.877) and SID (p<0.001; η_p^2=0.826). Pre-warm up SID was elevated for $NaHCO_3$ vs. placebo conditions (~7.0 meq.l^{-1}). The intermittent warm ups elicited a rise in [BLa^-] compared to the control warm ups (~6.75 mmol.l^{-1}). Extracellular ionic disturbances were only present prior to the TT

following CWSB with pre-TT SID greater for CWSB vs. IWSB (+7.0 meq.l^{-1}), IWP (+14.0 meq.l^{-1}) and CWP (+7.9 meq.l^{-1}). Absolute increase in [BLa^{-}] during the TT was greater for CWSB vs. IWSB (+7.05 mmol.l^{-1}). Post-TT [BLa^{-}] was greater for CWSB vs. CWP (+2.52 mmol.l^{-1}). Post-TT SID was elevated for $NaHCO_3$ vs. placebo conditions (~4.8 meq.l^{-1}). At 5 min post [BLa^{-}] was greater for CWSB vs. IWP (+1.80 mmol.l^{-1}) and CWP (+2.39 mmol.l^{-1}). At 5 min post SID was elevated for NaHCO3 vs. placebo conditions (~4.9 meq.l^{-1}). Mean±SD for [BLa^{-}] and SID response are displayed in **Figure 4 (A-B)**.

[INSERT **Figure 4 (A-B)** NEAR HERE]

Perceptual Responses

Four participants identified all experimental beverages, whereas four were unable to consistently distinguish between $NaHCO_3$ and placebo. Seven participants experienced some GI discomfort, with the most severe symptoms experienced by each participant during each experimental trial shown in **Table 1**. No treatment effects were observed for GI discomfort at baseline, pre-TT or post-TT (all p>0.05). Pre-warm up belching was exacerbated for IWSB vs. IWP (3.5 mm vs. 0 mm; Z=-1.997; p=0.046) and CWP (3.5 mm vs. 0 mm; Z=-2.207; p=0.027). Aggregate GI discomfort scores revealed mild symptom severity pre-warm up for IWSB (39±49 mm) and CWSB (16±30 mm), but not at pre-TT. All participants reported that GI discomfort did not negatively impact their performance.

[INSERT **Table 1** NEAR HERE]

Discussion

This study was the first to examine the effect of an ecologically valid, intermittent, sprint-based warm up and individualised $NaHCO_3$ ingestion on 4-km cycling TT performance in trained cyclists. Our novel findings were that time to completion and average power displayed moderate-to-large improvements for CWSB only, with almost no change in performance for IWSB. The small-to-moderate combined effects on performance in favour of $NaHCO_3$ ingestion (ΔCWSB/CWP vs. ΔIWSB/IWP) suggest that the intermittent warm up dampened the ergogenic capacity of $NaHCO_3$ ingestion. Elevated acid-base balance (HCO_3^-, pH), increased pre-exercise SID and greater post-exercise BLa^{-} offer explanations for performance benefits. $NaHCO_3$ ingestion resulted in mild GI discomfort pre-warm up, however these symptoms were typically reduced prior to the 4-km cycling TT.

Improvements in time to completion (5.8 s) and average power (9.9W) for 4-km cycling TT's were observed during CWSB compared to CWP. These results are consistent with previous findings reporting improved 4-km cycling TT performance following 0.3 g.kg^{-1} BM $NaHCO_3$ compared to placebo conditions.[10,12] There was however some variation in performance responses, with four participants improving above the smallest worthwhile change (>4.4 s), whereas three participants only experienced trivial improvements (<3.0 s). Several studies have reported no mean differences in 4-km cycling TT performance following $NaHCO_3$ ingestion,[8,9] although benefits might not occur consistently unless absolute change in HCO_3^- reaches a 6.0 mmol.l^{-1} 'zone of erogeneity' threshold.[4] These authors[8,9] failure to adopt a time to peak HCO_3^- strategy likely prevented participants from achieving peak alkalosis immediately pre-TT, in theory dampening the ergogenic potential. This concept has recently been challenged, with de Oliveira et al[28] claiming that a long-lasting window of ergogenic potential (+6.0 mmol.l^{-1}; 90-225 min) exists following capsule $NaHCO_3$ ingestion. An individualised approach is most important for solution administration as a large proportion of HCO_3^- is lost from the neutralisation of gastric acid,[13] and for smaller doses that display shorter peak ergogenic potential.[4] Future research should refine practical application of $NaHCO_3$

supplementation by comparing ergogenic benefits between ingestion strategies (solution vs. capsule) and timing protocols (standardised vs. time to peak), and examining factors that may account for inter-individual variation in performance responses.

The most practically significant finding of our study was that warm up strategy impacts the efficacy of individualised $NaHCO_3$ ingestion. Improvements in 4-km time to completion (5.0 s) and average power (10.7W) for CWSB compared to IWSB displayed moderate-to-large effect sizes. Moreover, the small-to-moderate combined effects on performance in favour of $NaHCO_3$ ingestion (ΔCWSB/CWP vs. ΔIWSB/IWP) confirm that the intermittent, sprint-based warm up mitigated the ergogenic effect of $NaHCO_3$ ingestion. These results are similar to studies employing sport specific warm up strategies,[8,14-16] and can be attributed to differences in pre-TT metabolic perturbation, primarily as the sprint efforts during the intermittent warm up would have resulted in greater accumulation of H^+ within the muscle.[1,3] Considering that HCO_3^- buffering mechanisms are partly responsible for the removal of these H^+ into extracellular compartments,[5] the enhanced buffering response will have been partially utilised pre-TT, thus dampening the ergogenic potential of $NaHCO_3$ ingestion. From an applied standpoint, these results advocate that practitioners adapt their warm up regimes to ensure ergogenic benefits following $NaHCO_3$ supplementation. Since the intermittent, sprint-based warm up alone had no effect on 4-km cycling TT performance, it is recommended that practitioners adopt evidence-based nutritional practices when designing pre-race strategies, as these may prove more beneficial to overall performance. The current intermittent warm up reflects pre-race programmes for individual pursuit events, however cyclists competing in maximal, shorter sprint races (~1 min) may adopt warm up strategies that further exacerbate pre-competition metabolic perturbation. Additional work is required to examine the impact of these sprint warm up strategies on the efficacy of $NaHCO_3$ during "all-out" sprint exercise.

Disturbances in acid-base balance (HCO_3^-, pH) and increased post-exercise BLa^- offer mechanistic insight to explain improved TT performance. Absolute change in HCO_3^- from baseline to pre-TT (+6.6 $mmol.l^{-1}$) was above the suggested 6.0 $mmol.l^{-1}$ threshold[4] and greater than increases from previous studies (~3.0-5.0 $mmol.l^{-1}$) reporting no performance benefits.[8,9] Participants only entered the TT in an alkalotic state during CWSB, but differences in absolute decline from pre- to post-TT are equally significant, as these infer whether an enhanced buffering response was present during exercise.[6] The absolute decline in HCO_3^- and pH was substantially higher for CWSB vs. IWSB, confirming that enhanced buffering capacity was utilised during the intermittent, sprint-based warm up. The induced alkalosis also likely prevented the allosteric inhibition of phosphofructokinase and glycogen phosphorylase, in turn up-regulating glycolytic activation.[29] Post-TT BLa^- was elevated by ~20% following $NaHCO_3$ ingestion, which was similar to previous studies.[6,10,11] The absolute increase from pre- to post-TT was much higher for CWSB vs. IWSB, thus further explaining differences in performance. These changes in BLa^- might reflect greater efflux rates from the muscle, and not only increased glycolytic energy production,[29] although it is likely that combined with the alkalosis partially accounted for the ergogenic benefits.

$NaHCO_3$ ingestion elevated SID above baseline levels, primarily attributable to increased Na^+ and reduced Cl^-. The intermittent warm up mitigated these increases in SID, which expands upon our mechanistic explanation for the differences in performance between $NaHCO_3$ trials. Pre-exercise changes in SID were consistent with previous findings,[6] although SID remained elevated by ~19% following $NaHCO_3$ post-TT. This discrepancy can be explained by greater metabolic perturbation during the hypoxic conditions employed previously. These ionic changes reflect greater protection of action potentials within T-systems, allowing for sustained excitation of working muscles.[1,7] The results cited in the present study only reveal changes occurring within extracellular compartments,[6] and do not infer whether alkalosis markedly increased ionic disturbances within contracting muscle.

Moreover, these changes in SID may have been exacerbated by differences in the molecular composition of Na^+ between the two experimental beverages (i.e. greater Na^+ content for 0.3 $g.kg^{-1}$ BM $NaHCO_3$). Pilot testing revealed it was not possible to taste-match an equimolar sodium chloride dose (0.21 $g.kg^{-1}$ BM), therefore future research should administer $NaHCO_3$ via capsules to determine whether similar extracellular ionic changes are observed.

Our findings are consistent with previous studies reporting mild GI discomfort following $NaHCO_3$ ingestion,[6,10,22] although these symptoms were reduced pre-TT and did not impair performance. There was also a large degree of inter- and intra-individual variation, with two participants reporting severe diarrhoea and bowel urgency pre-warm up for one $NaHCO_3$ trial, but not the other. The severity of symptoms might have been reduced following capsule administration, or by co-ingesting a high-carbohydrate meal,[13] but the latter was not feasible with typically only a short window (~45 min) between ingestion and warm up. Further investigation is warranted to better understand variability in GI discomfort, with athletes recommended to trial $NaHCO_3$ ingestion during training to inform decisions regarding practical application of the supplement.

Practical Applications

An intermittent, sprint-based warm up strategy mitigates the ergogenic potential of $NaHCO_3$ ingestion by utilising the enhanced extracellular buffering capacity prior to commencing the 4-km cycling TT. Improvements in performance were only observed when individualised $NaHCO_3$ ingestion was combined with a steady state, control warm up. There was a large degree of variation in performance responses and GI discomfort following $NaHCO_3$ ingestion, therefore athletes are recommended to trial the supplement during training before use in competition. Practitioners and athletes should opt for an individualised time-to-peak HCO_3^- ingestion strategy and alter warm up strategies to maximise the performance benefits of $NaHCO_3$ ingestion.

Conclusion

This study was the first to demonstrate that an ecologically valid, intermittent, sprint-based warm up reduces the ergogenic capacity of individualised $NaHCO_3$ ingestion on 4-km cycling TT performance in cyclists. Metabolic perturbation associated with the intermittent warm up dampened the ergogenic potential of $NaHCO_3$. Improvements in 4-km TT completion time and average power following $NaHCO_3$ ingestion and the control warm up were attributed to enhanced HCO_3^- buffering response, up-regulation of glycolytic activation and sustained excitation of contracting muscles. $NaHCO_3$ ingestion resulted in mild GI discomfort, although this did not impact performance and displayed a large degree of inter- and intra-individual variation. Our results provide practitioners with evidence-based practice advocating the inclusion of individualised sodium bicarbonate supplementation within pre-race regimes, as this proves more beneficial for improving 4-km cycling TT performance than an intermittent, sprint-based warm up strategy.

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Conflict of interest

William Gurton, Steve Faulkner and Ruth James can confirm that there are no competing interests related to the study outcome or the supplement investigated.

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Figure legends

Figure 1 Mean differences (heavily bolded line) and inter-individual variation for 4-km cycling TT performance.

Figure 2 Pacing per km for average power during the 4-km cycling TT's. Data are presented as mean±SD; Some error bars removed for clarity.

Figure 3 (A-B) Mean±SD blood bicarbonate (**A**) and pH (**B**) response from baseline to 5 min post. Symbols denote significant difference (p<0.05): * IWSB and CWSB vs. IWP and CWP; ** CWSB vs. IWSB, IWP and CWP.

Figure 4 (A-B) Mean±SD blood lactate (**A**) and strong ion difference (**B**) response from baseline to 5 min post. Symbols denote difference (p<0.05): * IWSB and CWSB vs. IWP and CWP; ** CWSB vs. IWSB, IWP and CWP; $^{+}$ IWSB and IWP vs. CWSB and CWP; $^{++}$ CWSB vs. CWP; $^{+++}$ CWSB vs. IWP and CWP.

Figures

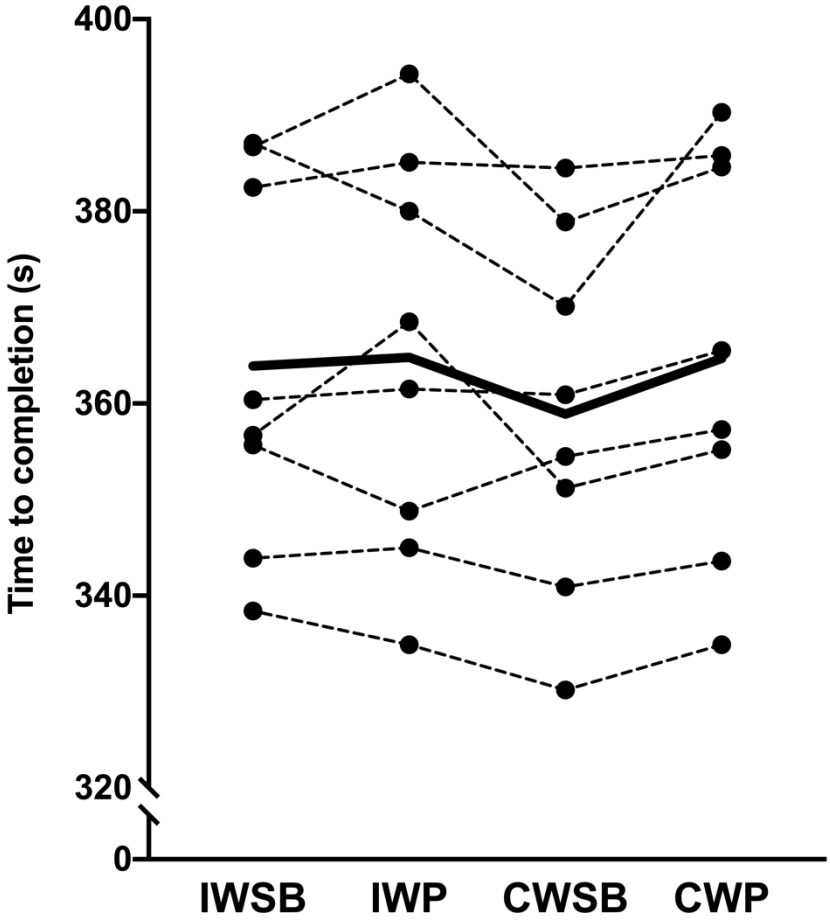

Figure 1

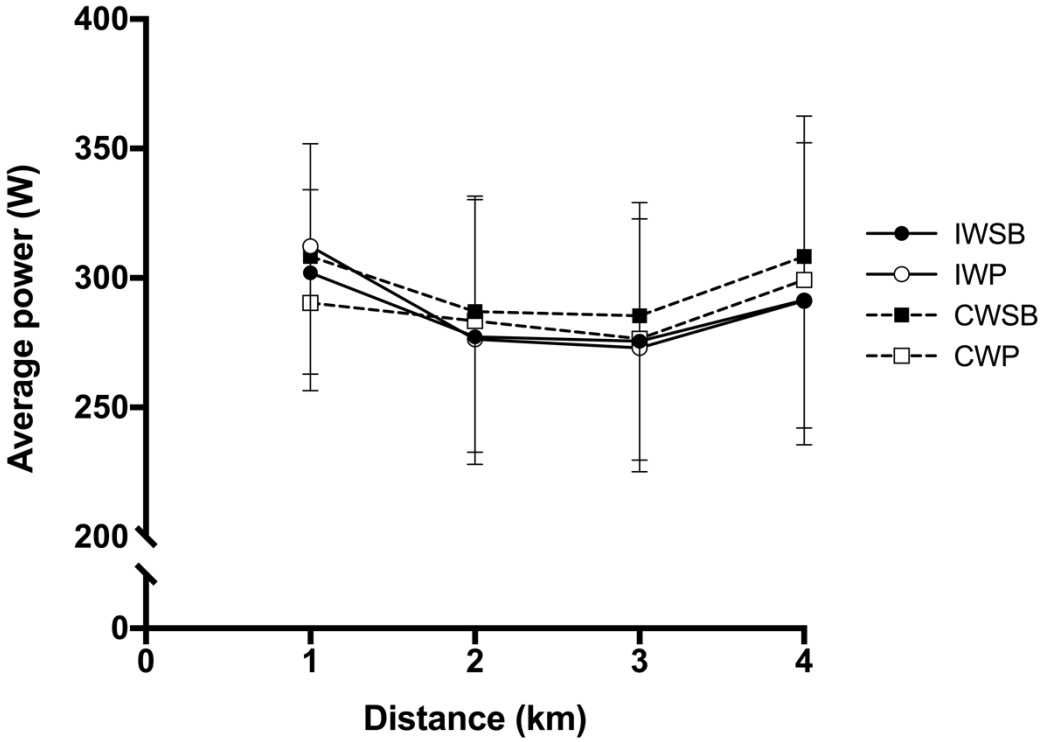
400
350
300
250
200
0
Average power (W)
0
1
2
3
4
Distance (km)
IWSB
IWP
CWSB
CWP

Figure 2

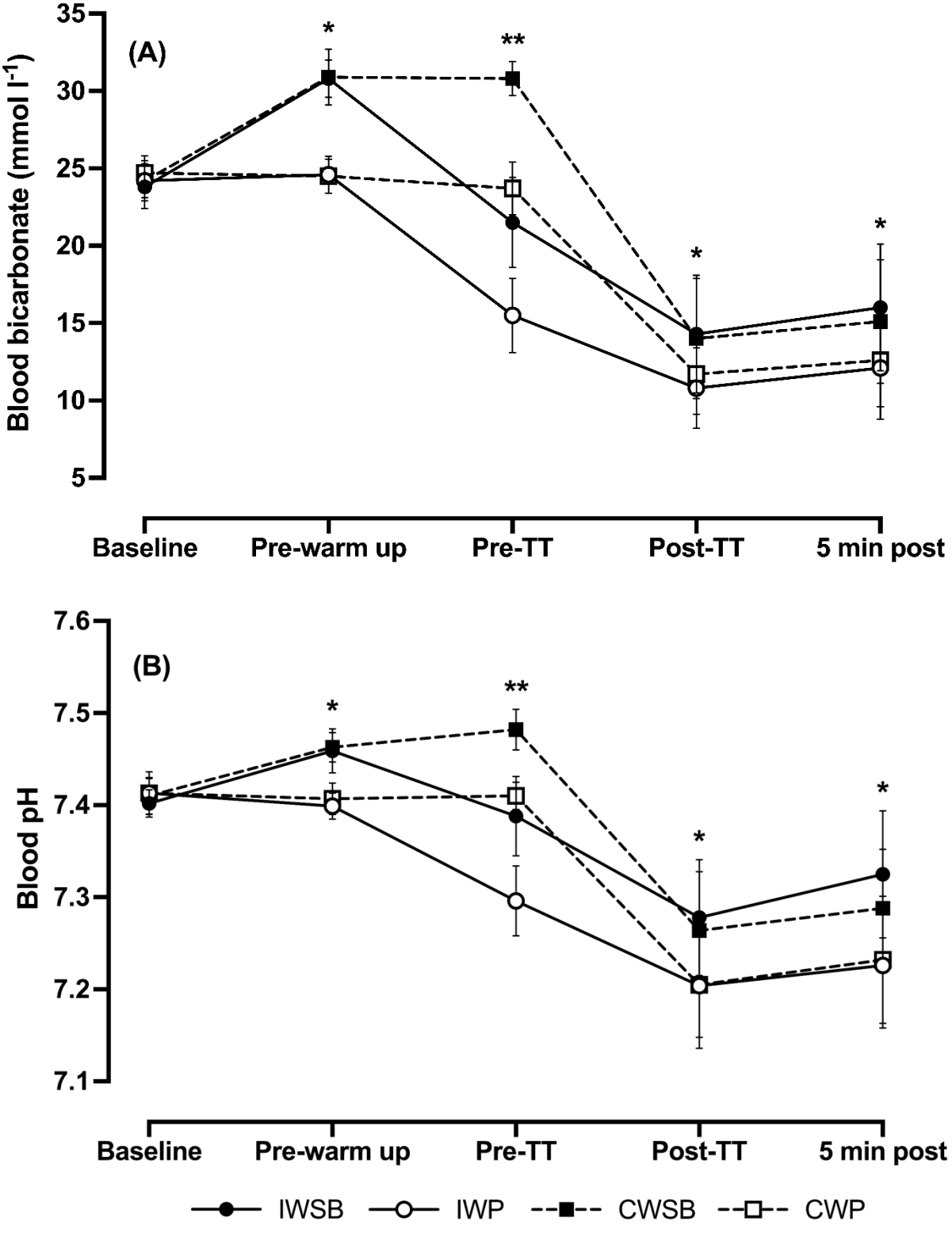
(A)
Blood bicarbonate (mmol l-1)
35
30
25
20
15
10
5
*
**
*
*
Baseline
Pre-warm up
Pre-TT
Post-TT
5 min post
(B)
Blood pH
7.6
7.5
7.4
7.3
7.2
7.1
*
**
*
*
Baseline
Pre-warm up
Pre-TT
Post-TT
5 min post
IWSB
IWP
CWSB
CWP

Figure 3 (A-B)

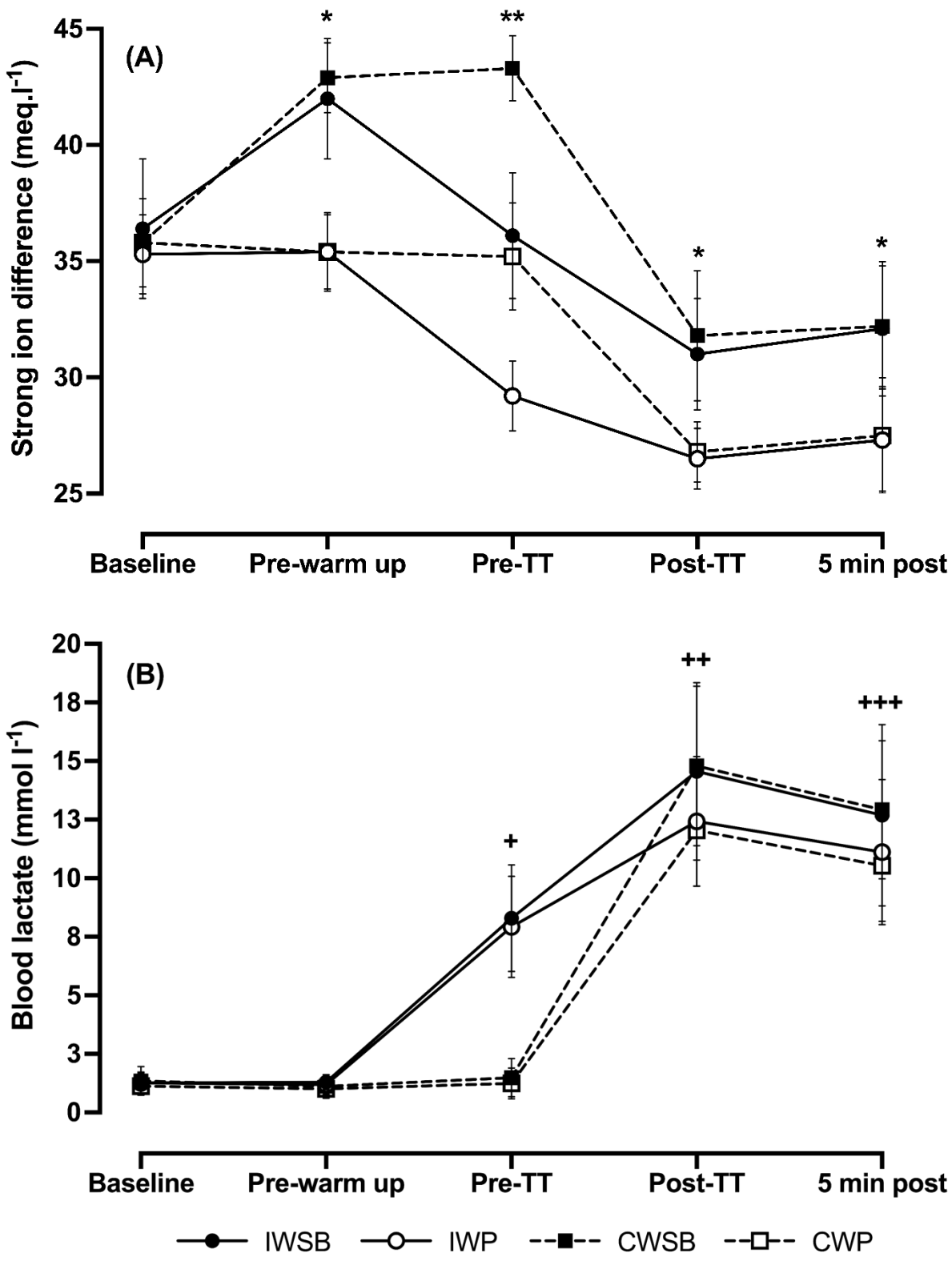
(A)
Strong ion difference (meq.l-1)
45
40
35
30
25
*
**
*
*
Baseline
Pre-warm up
Pre-TT
Post-TT
5 min post
(B)
Blood lactate (mmol l-1)
20
18
15
13
10
8
5
3
0
+
++
+++
Baseline
Pre-warm up
Pre-TT
Post-TT
5 min post
IWSB
IWP
CWSB
CWP

Figure 4 (A-B)

Table 1 The severest GI symptoms experienced by each participant during each experimental trial

Participant	IWSB	IWP	CWSB	CWP
1	**AD** *(21)*	Flatulence *(3)*	Nausea *(11)*	GF *(3)*
2	GF *(5)*	Flatulence *(2)*	**Diarrhoea** *(45)*	GF *(2)*
3	**Belching** *(25)*	Nausea *(4)*	Belching *(5)*	Nil *(0)*
4	Nausea *(22)*	Nausea *(20)*	Belching *(23)*	**Nausea** *(24)*
5	GF *(3)*	**AD** *(5)*	GF *(3)*	Belching *(1)*
6	**Vomiting** *(21)*	Nil *(0)*	Nil *(0)*	Nil *(0)*
7	**BUR** *(67)*	Nil *(0)*	Diarrhoea *(21)*	Nil *(0)*
8	Nil *(0)*	Nil *(0)*	Nil *(0)*	Nil *(0)*

Abbreviations: IWSB, intermittent warm up + sodium bicarbonate; IWP, intermittent warm up + placebo; CWSB, control warm up + sodium bicarbonate; CWP, control warm up + placebo; AD, abdominal discomfort; GF, gut fullness; BUR, bowel urgency rating.

Severest symptom for each participant is highlighted in bold; symptom severity score (on a scale of 0 to 100) is displayed in parenthesis.

Mr William H. Gurton, BSc

Sport, Health and Performance Enhancement Research Centre

Department of Sport Science, Nottingham Trent University

11th June 2020

Dear Editor,

My colleagues and I would like to submit the manuscript "Effect of warm up and sodium bicarbonate ingestion on 4-km cycling time trial performance" to the Journal of Sports Physiology and Performance. We state that: "The manuscript is original research and has not previously been published, and is not being considered for publication elsewhere until a decision is made as to its acceptability by the IJSPP Editorial Review Board".

The final version of the manuscript has been read and approved by all listed co-authors. Each author has made substantial contributions to the research design, statistical analysis, data interpretation and drafting of this journal article.

We are confident that this is novel and rigorous research. The present findings are the first to demonstrate that an ecologically valid, intermittent warm up reduces the ergogenic capacity of individualised sodium bicarbonate ingestion on 4-km cycling time trial performance in cyclists. This highlights the potential detrimental effect of warm up strategy on the efficacy of extracellular buffering agents for improving performance, which is thought to be of practical significance to coaches and athletes.

We look forward to hearing back in due course regarding the nature of your decision.

Yours Sincerely,

MRes Exercise Physiology

Email: william.gurton2019@my.ntu.ac.uk

sport, health and performance enhancement