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PRIORITY REPORT

Sodium bicarbonate ingestion improves repeated high-intensity cycling performance in the heat

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ABSTRACT

The purpose of this study was to investigate the effect of sodium bicarbonate ingestion on performance and recovery of the Wingate test during exercise in the heat. At 30 °C (~50% relative humidity), ten male team sport athletes (mean values ± SD; age = 22 ± 4 y; body mass = 76 ± 9 kg) completed two 30s Wingate tests using a resistive load of 7.5% of body mass separated by 5 min of active recovery. They consumed either sodium bicarbonate (0.5g·kg^{-1} body mass) or sodium chloride as a taste-matched placebo (0.2g·kg^{-1} body mass) divided into 3 doses at 4h intervals on the day of each test. Performance measures included peak power, rate of fatigue and anaerobic capacity whilst physiological measures of capillary pH, bicarbonate, base excess/deficit and lactate were taken at rest and 3 min following each Wingate test. At all time-points (baseline and following both Wingate tests) capillary pH, bicarbonate and base excess/deficit were higher with sodium bicarbonate, whilst lactate was higher following both Wingate tests with sodium bicarbonate (all $p < 0.05$). Anaerobic capacity was similar during Wingate 1 but was higher with sodium bicarbonate during Wingate 2 ($p < 0.05$), with peak power ($p < 0.05$) but not rate of fatigue ($p > 0.05$) different between the trials during Wingate 2. When performing high-intensity anaerobic exercise in the heat, sodium bicarbonate ingestion improves recovery and repeated exercise performance likely through its known effects for reducing metabolic acidosis.

Abbreviations: WAnT: Wingate anaerobic test

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Acid-base balance; buffer; alkalosis; Wingate test; recovery; anaerobic; sprint

Introduction

Ingestion of sodium bicarbonate ($NaHCO_3$) as an ergogenic aid has been researched extensively as a buffering mechanism that effectively attenuates metabolic acidosis, consequently delays fatigue, and improves performance during high-intensity/maximal, anaerobic exercise [1]. Many athletes are required to perform such maximal efforts repeatedly with minimal recovery times, often in warm-to-hot environments/climates, during the hottest season, or at the hottest part of a day. However, surprisingly there has been no investigation into the effect of $NaHCO_3$ on performance and recovery of such exercise with an ambient heat load.

Whether $NaHCO_3$ ingestion should prove as effective during high-intensity exercise accompanied by ambient thermal stress as compared to more moderate environments appears equivocal. Firstly, although ATP utilization is increased during aerobic (i.e. < 85% aerobic maximum) exercise in the heat predominantly by anaerobic pathways [2,3], for maximal efforts (i.e. anaerobic, that can only be sustained < 1 min) the metabolic response (i.e. pH and/or lactate) remains unchanged even for repeated bouts in the heat [4–6]. Secondly, ambient heat stress does not impair [6] but instead enhances [4,5,7,8] high-intensity exercise, as opposed to aerobic exercise [9,10].

Therefore, the above evidence indicates that $NaHCO_3$ ingestion would be only as effective or even less so during maximal exercise in the heat as compared to cooler conditions. Thus, the purpose of this study was to determine the efficacy of $NaHCO_3$ ingestion on performance and recovery of repeated maximal intensity cycling with ambient heat stress.

Materials and methods

Ten healthy males volunteered to participate in the study. Their mean (SD) physical characteristics were,

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age: 22 (4) y, height: 1.77 (0.06) m, weight: 76 (9) kg. All participants had been competitive in team sports and trained (including gym sessions) or competed regularly ≥3 times per week for at least 2 y, thereby ensuring familiarity with repeated high-intensity/maximal efforts; furthermore, each had previous experience of completing a Wingate anaerobic test (WAnT). Each participant was fully informed of all potential risks and experimental procedures, after which informed written consent was obtained. All experimental procedures and protocols were approved by the Institutional Human Ethics Committee and performed in accordance with the latest revision of the *Declaration of Helsinki*.

Participants visited the laboratory on three separate occasions: 1) anthropometric measures followed by full experimental familiarisation, 2–3) experimental trials. The experimental familiarisation was a separate visit whereby participants completed the full experimental trial (see below) of cycling, however, without ingestion of any solution. The experimental trials were completed using a randomised crossover design, with these trials separated by 7 days, conducted at the same time of day (±1 h), and the day of and prior to any experimental trial marked by abstinence from alcohol and exercise and only habitual caffeine use (as abstinence would confound from withdrawal effects). Additionally, participants were asked to replicate their diet during the first experimental visit for the subsequent trial to ensure a similar metabolic state. Experimental trials consisted of the treatment ($NaHCO_3$, BIC) and a placebo (NaCl, PLA) dissolved in fruit-flavoured cordial. All trials were completed on the same cycle ergometer (Monark, Varberg, Sweden), where participants' set-up (e.g. seat/handle bar height etc.) was customised and replicated for each subsequent visit.

On arrival to the laboratory participants voided and changed into appropriate clothing (sports shoes, shorts and t-shirt) then remained seated in a temperate environment (20 °C) for 15 min. A 50 μL fingertip resting blood sample was collected into a heparinized glass capillary tube, after which participants entered the environmental chamber maintained at 30 °C (~50% relative humidity), where a fan located in front of the ergometer provided an airflow of 20 $km \cdot h^{-1}$. They then completed a 5-min warm-up of cycling at 100 W before completing the first WAnT. The WAnT was completed on a friction-loaded ergometer (Monark, Varberg, Sweden) using a resistive load of 7.5% of body mass, with participants required to start from stationary with their pedals at a 45° angle and the preferred leg above horizontal and forward, following a 3-s countdown. Cadence was recorded every 5 s and power output calculated from friction load and flywheel velocity. The highest and lowest 5 s values were used to determine peak power (W) and rate of fatigue (%), whilst the sum of all 5 s values determined the anaerobic capacity (kJ). Five min of active recovery (50 W) separated WAnT 1 and 2, and exercise was concluded by a 5-min cool-down (50 W). Three min following each WAnT a 50 μL fingertip blood sample was taken. All capillary blood samples were analyzed immediately for determination of pH, bicarbonate (HCO_3^-), base excess/deficit and lactate via an automated analyzer (Radiometer, Brønshøj, Denmark).

Participants were given a solution that incorporated $NaHCO_3$ (Pams Products Ltd, Auckland, New Zealand; $0.5 g \cdot kg^{-1}$ body mass) or NaCl (Pams Products Ltd, Auckland, New Zealand; $0.2 g \cdot kg^{-1}$ body mass) as a taste-matched placebo (determined from pilot testing). This was mixed with 15 $ml \cdot kg^{-1}$ body mass of a low-calorie orange-flavored drink (Baker Halls & Co. Auckland, New Zealand) made to the manufacturer's recommendations to further blind participants. This solution was then divided into three (iso-volumetric) bottles with participants consuming each bottle at 4h intervals throughout the experimental day (0800h with breakfast, 1200h with lunch, and 1600h with a small snack). All experimental testing commenced at 1700 h. This dosing regimen provides a favorable blood biochemical profile following the first day of supplementation and without the gastro-intestinal discomfort often associated with an acute bolus [11].

As the focus of the present study was the metabolic and performance changes associated with $NaHCO_3$ ingestion, and that previous investigations have demonstrated minimal and equivalent increases in core and muscle temperatures between repeated maximal exercise of similar or greater duration between moderate and hot environments [7,8,12], no measurement of body temperatures was made. Although an acknowledged study (de-)limitation, this is further supported by the most common indices of core temperature (rectal, pill) exhibiting a considerably longer lag time than the current protocol duration [13], making it unlikely that any differences would be detected.

Table 1. Mean ± SD values (n = 10) for measures of capillary pH, bicarbonate (HCO_3^-), base excess/deficit and lactate for placebo (NaCl) and treatment ($NaHCO_3$).

	NaCl			$NaHCO_3$		
	Rest	**WAnT 1**	**WAnT 2**	**Rest**	**WAnT 1**	**WAnT 2**
pH	7.43 ± 0.02	7.23 ± 0.04	7.15 ± 0.05	7.48 ± 0.03	7.30 ± 0.03	7.22 ± 0.04
HCO_3^- ($mmol \cdot L^{-1}$)	25.8 ± 1.1	15.1 ± 2.3$^{\#}$	9.5 ± 1.7$^{\#*}$	32.9 ± 1.8†	18.6 ± 1.3$^{\#\dagger}$	12.7 ± 1.3$^{\#*\dagger}$
Base Excess/Deficit ($mmol \cdot L^{-1}$)	1.4 ± 1.1	−11.5 ± 2.5$^{\#}$	−17.8 ± 2.1$^{\#*}$	8.5 ± 1.8†	−7.3 ± 1.4$^{\#\dagger}$	−13.7 ± 1.8$^{\#*\dagger}$
Lactate ($mmol \cdot L^{-1}$)	1.3 ± 0.3	14.6 ± 3.2$^{\#}$	20.6 ± 3.6$^{\#*}$	1.6 ± 0.6	16.6 ± 2.2$^{\#\dagger}$	22.9 ± 3.1$^{\#*\dagger}$

Footnotes: Measures taken at rest prior to and following first (WAnT 1) and second (WAnT 2) Wingate anaerobic tests. $^{\#}$Significant difference to corresponding Rest value; *Significant difference to corresponding WAnT 1 value; †Significant difference to corresponding NaCl value

All statistical analyses were performed with SPSS software for windows (IBM SPSS Statistics 20, NY, USA). Descriptive values were obtained and reported as means and standard deviation (SD), unless stated otherwise. Levene's test was used to ensure data did not differ substantially from a normal distribution. Resting data (for blood variables) were first analyzed using a paired samples t-test. Data repeated over time were analyzed by two-way (treatment × time) ANOVA. Sphericity was assessed and where the assumption of sphericity could not be assumed, adjustments to the degrees of freedom were made ($\varepsilon > 0.75$ = Huynh-Feldt; $\varepsilon < 0.75$ = Greenhouse-Geisser). Following a significant F test *post-hoc* pairwise analyses were performed using a paired samples t-test (Bonferroni correction where relevant), with statistical significance set at $P \leq 0.05$. Partial eta-squared (η_p^2) is reported as a measure of effect size, with demarcations of small (<0.09), medium (>0.09 and <0.25) and large (>0.25) effects, respectively [14].

Results

All participants completed both trials successfully and none complained of any gastro-intestinal (or other) symptoms; however, comments were received that the taste of both drinks was not optimal ("too salty").

Ingestion of BIC caused an increase in HCO_3^- as a function of time (treatment × time: $p < 0.001$, η_p^2 = 0.81; Table 1) such that the increase in HCO_3^- was more pronounced at rest (7.1 ± 1.8 $mmol \cdot L^{-1}$) than following each WAnT (WAnT 1: 3.5 ± 2.0 $mmol \cdot L^{-1}$, WAnT 2: 3.2 ± 1.5 $mmol \cdot L^{-1}$) when compared with PLA. The results for base excess/deficit mirrored HCO_3^- (treatment × time: $p < 0.001$, η_p^2 = 0.69; Table 1). For pH main effects of treatment (p = 0.001, η_p^2 = 0.83; Table 1) and time ($p < 0.001$, η_p^2 = 0.97; Table 1) were observed such that pH was higher (0.06 ± 0.03) with BIC and was reduced from resting following WAnT 1 (−0.19 ± 0.04) and WAnT 2 (−0.27 ± 0.05). Lactate was similar at rest (p = 0.18) but differed between treatments as a function of time (treatment × time: p = 0.03, η_p^2 = 0.40; Table 1).

For the repeated WAnTs, anaerobic capacity differed between treatments as a function of time (treatment × time: p = 0.04, η_p^2 = 0.47; Table 2) such that PLA 2 was lower than PLA 1 by −11 ± 6% or −2.0 ± 1.4 kJ, whilst work was maintained between BIC 1 and 2. Therefore, more work was completed during BIC 2 than PLA 2 (by 5 ± 4% or 0.8 ± 0.6 kJ). Differences in performance were not a function of rate of fatigue as no main or interaction effects were observed (all $p >$ 0.53, $\eta_p^2 < 0.06$). Rather, peak power differed between treatments as a function of time (treatment × time: p = 0.01, η_p^2 = 0.63; Table 2) such that PLA 2 was lower than PLA 1 by −8 ± 8% or -64 ± 72 W, whilst power was maintained between BIC 1 and 2.

Discussion

This is the first study to determine whether $NaHCO_3$ influences repeated high-intensity cycling performance under conditions of heat stress. The main finding is that $NaHCO_3$ ingestion sustains peak power in a repeated maximal effort without affecting the rate of fatigue, thereby maintaining work completed as compared to a placebo. The mechanism of action is most likely the effect of a greater pre-exercise buffering capacity that allows a favourable acid-base balance, thus attenuating exercise-induced metabolic acidosis.

Table 2. Mean ± SD values (n = 10) for measures of peak power, rate of fatigue and work completed for placebo (NaCl) and treatment ($NaHCO_3$).

	NaCl		$NaHCO_3$	
	WAnT 1	WAnT 2	WAnT 1	WAnT 2
Peak Power (W)	744 ± 141	680 ± 125*	731 ± 128	715 ± 114
Rate of Fatigue (%)	34 ± 7	32 ± 14	35 ± 9	34 ± 10
Work Completed (kJ)	18.5 ± 2.8	16.4 ± 2.3*	18.4 ± 2.4	17.2 ± 2.1†

Footnotes: Measures during first (WAnT 1) and second (WAnT 2) Wingate anaerobic tests. *Significant difference to corresponding WAnT 1 value; †Significant difference to corresponding NaCl value

The present results demonstrate that $NaHCO_3$ prevents the ~8% reduction in peak power observed when a repeated WAnT is performed with a placebo, thereby increasing the anaerobic work completed by ~5% during this repeated bout. The magnitude of this positive effect (all significant results = large effect sizes) agrees with a recent meta-analysis [1] and extends the ergogenic effect observed to a warm environment. Therefore, $NaHCO_3$ ingestion is equally effective during maximal exercise in hot as moderate environments. Interestingly, this effect for $NaHCO_3$ (during exercise in the heat) is similar in magnitude to those reported for warm-hot ambient conditions when compared to more temperate [4,5,7,8] although the mechanisms responsible likely differ. Brief (~10 min) periods of active and passive warming, and in combination, have minimal effect on the body's core temperature but do substantially raise the temperature of the active musculature [7,8]; this is known to facilitate improvements in force/velocity and power/velocity characteristics through enhanced rates of force production and relaxation due to greater nerve conductivity and muscle tension [5,7]. Whereas, additional HCO_3^- increases the extracellular buffering capacity and enhances H^+ efflux from the muscle into the blood, which maintains muscle pH closer to normal; this allows the contractile process and glycolytic ATP resynthesis to continue under more favourable conditions [15,16].

That performance during WAnT 1 was similar despite HCO_3^- and base excess already being elevated with $NaHCO_3$ is surprising, although a recent meta-analysis reported that only 40% of the studies reviewed observed an ergogenic effect with $NaHCO_3$, and that repeated bouts provide significantly less of an effect than single bouts [1]. Therefore, at least for WAnT 1 there appears to be a dissociation between the $NaHCO_3$-induced changes in acid-base balance and performance. It is without question that high-intensity exercise leads to a decline in performance (fatigue), and is associated with peripheral/muscular property changes to the action potential, extracellular and intracellular ions and metabolites [17]. However, determining the causal factor(s) of this fatigue remains difficult and complex as common 'culprits' such as pH and lactate are not the only or primary determinant [18], especially as it has been established that H^+ is released not only by a lactic acidosis [19]. Thus, although lactate was only different between the trials after WAnT 1, whether this contributed to the performance differences seen during WAnT 2 remains speculation as it is known that cell function is not negatively affected by lactate [20].

From a practical perspective, these results could be viewed favourably by sports that are often performed in warm-hot environments and require repeated maximal power e.g. track cycling, short-duration outdoor athletics etc. Nevertheless, a cautionary note concerns the external validity of these results as most athletes would perform a substantial warm-up prior to competition, and thus future research should address the threshold at which (core) body temperature becomes a limiting factor, and whether $NaHCO_3$ ingestion still proves ergogenic during hyperthermia as this would more closely simulate practice [21].

In summary, ingesting a chronic, divided dose of $NaHCO_3$ causes blood stores of HCO_3^- and base excess to increase along with an alkalosis, effects that are (relatively) maintained during repeated WAnTs with environmental heat stress. This physiological effect appears like those at more moderate environmental temperatures. Total (anaerobic) work completed is maintained with $NaHCO_3$ compared to a placebo, demonstrating an improved recovery, and this is likely due to peak (initial) power being sustained from WAnT 1 as rate of fatigue does not differ. Therefore, performance improvements due to $NaHCO_3$ also appear like those at more moderate environmental temperatures.

Disclosure of potential conflicts of interest

No potential conflicts of interest are disclosed.

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