Effects of Sodium Bicarbonate Ingestion on Performance and Perceptual Responses in a Laboratory-Simulated BMX Cycling Qualification Series

Mikel Zabala,[1,4] Bernardo Requena,[2] Cristóbal Sánchez-Muñoz,[1,4] Juan José González-Badillo,[2] Inmaculada García,[1] Vahur Ööpik,[3] and Mati Pääsuke[3]

[1]Department of Physical Education and Sport, University of Granada, Granada, Spain; [2]Faculty of Sport, Pablo de Olavide University, Sevilla, Spain; [3]Institute of Exercise Biology and Physiotherapy, University of Tartu, Estonia; and [4]Spanish Cycling Federation, Madrid, Spain

Abstract

Zabala, M, Requena, B, Sánchez-Muñoz, C, González-Badillo, JJ, García, I, Ööpik, V, and Pääsuke, M. Effects of sodium bicarbonate ingestion on performance and perceptual responses in a laboratory-simulated BMX cycling qualification series. *J Strength Cond Res* 22(5): 1645–1653, 2008—The objective of this study was to examine the effect of sodium bicarbonate ($NaHCO_{3-}$) ingestion on performance and perceptual responses in a laboratory-simulated bicycle motocross (BMX) qualification series. Nine elite BMX riders volunteered to participate in this study. After familiarization, subjects undertook two trials involving repeated sprints (3 × Wingate tests [WTs] separated by 30 minutes of recovery; WT1, WT2, WT3). Ninety minutes before each trial, subjects ingested either $NaHCO_{3-}$ or placebo in a counterbalanced, randomly assigned, double-blind manner. Each trial was separated by 4 days. Performance variables of peak power, mean power, time to peak power, and fatigue index were calculated for each sprint. Ratings of perceived exertion were obtained after each sprint, and ratings of perceived readiness were obtained before each sprint. No significant differences were observed in performance variables between successive sprints or between trials. For the $NaHCO_{3-}$ trial, peak blood lactate during recovery was greater after WT2 ($p < 0.05$) and tended to be greater after WT3 ($p = 0.07$), and ratings of perceived exertion were not influenced. However, improved ratings of perceived readiness were observed before WT2 and WT3 ($p < 0.05$). In conclusion, $NaHCO_{3-}$ ingestion had no effect on performance and RPE during a series of three WT simulating a BMX qualification series, possibly because of the short duration of each effort and the long recovery time used between the three WTs. On the contrary, $NaHCO_{3-}$ ingestion improved perceived readiness before each WT.

Key Words bicarbonate ingestion, bicycle motocross, Wingate test, performance, RPE, perceived readiness

Address correspondence to Mikel Zabala, mikelz@ugr.es.

22(5)/1645–1653

Journal of Strength and Conditioning Research

Introduction

Bicycle motocross (BMX) is a relatively new Olympic discipline consisting of repeated cycling trials across an irregular sand track with bends and jumps (approximately 350 m in about 40 seconds). The aim is to reach the finish line in the best position of eight riders. In the last decade, BMX has received increased interest and an increased number of competitions across the world, partly because of its inclusion in the 2008 Olympic Games in Beijing, China. Each competition usually involves at least the three qualification series, quarterfinals, semifinals, and final (six laps). Between each series, there is a recovery period of about 30 minutes. Recently, the main physiological demands of the European BMX championships were described. This study reported maximum blood lactate concentrations ([BLa]) of up to 18.6 $mmol{\cdot}L^{-1}$ (mean of 8.55 $mmol{\cdot}L^{-1}$) and a maximum heart rate (HR) of 90% of the HR reserve (mean of HRreserve, 81.55%). On the basis of the HR, [BLa], and rating of perceived exertion (RPE) data, and competitors involving mainly anaerobic lactic metabolism, the authors suggested that the physiological demands of one BMX trial would be similar to the 30-second Wingate anaerobic test (WT). Therefore, for the present study the WT was used to simulate the physiological demands of a BMX race in laboratory conditions.

During the past decades, numerous studies have demonstrated that increases in the extracellular buffer concentration, via the oral ingestion of an alkaline solution such as sodium bicarbonate ($NaHCO_{3-}$), may enhance human exercise performance (5,8,17,24–26,33,34,39,40). The suggested beneficial effects of metabolic alkalosis include an increase in extracellular proton buffer capacity (15,17,41), increased muscle phosphofructokinase, phosphorylase and piruvate dehydrogenase activities (10), enhanced muscle Lac^- and H^+ release from working muscles (20,37), and a preservation of membrane excitability during muscle fatigue by its effect on K^+, Na^+, and Cl^- fluxes (39). In general, studies that have found an increase in exercise performance after $NaHCO_{3-}$ ingestion used intermittent or continuous exercise regimens that produced a large acid-base disturbance (17,34). During continuous dynamic exercises, performance has been generally improved when the protocol selected exhausted the subjects in 1–10 minutes (34). However, when high-intensity exercises of shorter duration (30–40 seconds) were examined, conflicting results were reported (12,17,34). The studies that have analyzed the effect of $NaHCO_{3-}$ administration on WT performance have shown ergogenic (7,13) and nonergogenic benefits (23,24,30). The reason for these conflicting results for WT is not clear, and, traditionally, it has been proposed that during WT, maximum buffering capacity is not used to the full, and so the ergogenic benefits are limited (24). However, all the above-mentioned studies were performed in nontrained subjects. It is well known that elite sprinters (100–200 m) produce an extremely high amount of H^+ and Lac^- during competition. ^{31}P-MRS studies have shown that as sprint trained athletes during maximal short-term efforts present a greater force production capacity associated with a greater systemic acidosis (lower intramuscular pH [pH_i] and a greater percentage of CrP breakdown) in comparison with untrained or endurance trained subjects (6,14). Thus, for the present study we hypothesized that in trained, elite sprint cyclists, the effects of $NaHCO_{3-}$ ingestion on WT performance should be more significant than those published previously in nontrained subjects.

To closely simulate a BMX qualification series, we designed an exercise protocol composed by three WT interspersed by a 30-minute recovery interval. Only one study (30) has reported the effects of $NaHCO_{3-}$ loading on a series of repeated WTs interspersed by 6-minute recovery periods, showing a small, but nonsignificant, effect on cycling performance. This study was also performed with nontrained subjects. No studies have been reviewed measuring the effects of $NaHCO_{3-}$ loading on series of WTs interspersed by longer recovery time intervals.

On the other hand, several studies (36,42,43) have demonstrated lower RPE during high-intensity exercise after $NaHCO_{3-}$ ingestion. Reductions in RPE may subsequently influence how well prepared an athlete feels to perform a subsequent exercise bout. However, the effect of bicarbonate loading on a competitor's RPE and perceived readiness after longer durations of recovery (more than 5 minutes) has not been studied.

In light of the increased interest in BMX performance and competition, and the widespread use of alkalinizants between elite athletes (34), the aim of the present study was to examine the effect of $NaHCO_{3-}$ loading on a laboratory-simulated BMX qualification series. We tested the hypothesis that the ingestion of $NaHCO_{3-}$ in elite BMX cyclists would improve their performance in the three subsequent WTs, reduce the subjects' RPE for each WT, and improve their perceptions of readiness to perform subsequent WTs.

METHODS

Experimental Approach to the Problem

During the experiment, the subjects were taking part in an official monitoring phase with the national team, so their eating and physical activity patterns were controlled accurately. The experimental phase took place during the end part of the preseason period. All the subjects visited the laboratory on three occasions. On the first visit, subjects were familiarized with the test procedure (Figure 1). Experimental data were collected during the subsequent two visits. The two treatment conditions, $NaHCO_{3-}$ ingestion ($NaHCO_{3-}$) and placebo (PLC), were administered in a counterbalanced, crossover, randomly assigned, double-blind manner, with

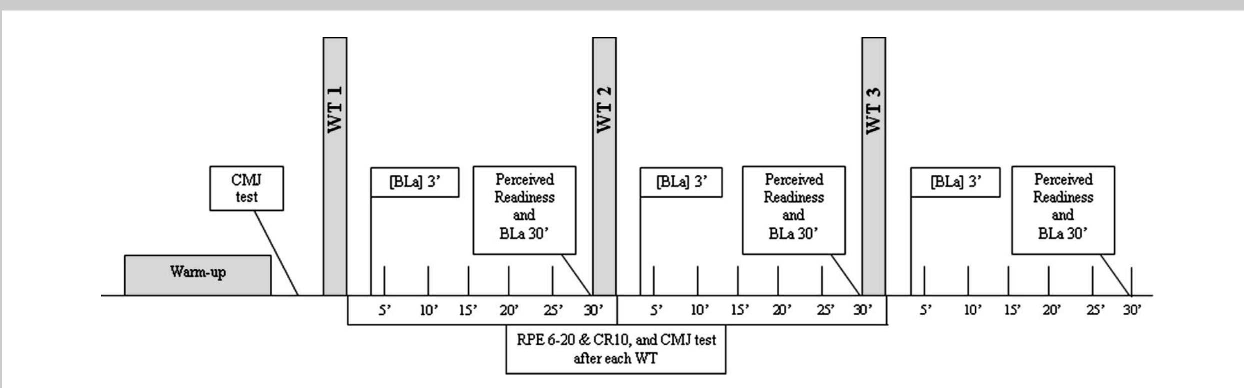

Figure 1. Experimental protocol.

each trial separated by four days (Figure 1). Each subject was instructed to refrain from caffeine, alcohol, and exercise for 24 hours before each trial, and studies were carried out at the same time of day.

Subjects

Nine elite BMX riders from the Spanish National Team volunteered to participate in this study. Their mean (± *SD*) age, height, and body mass were 19.4 ± 2.3 years, 174.5 ± 6.8 cm, and 73.8 ± 9.9 kg, respectively. Their training experience was 8–12 years. All the cyclists studied were full-time semi-professionals who trained 4–6 hours per day. Subjects were experienced in all testing procedures as a result of their performance in previous studies (more than eight times in the last 2 years). None of the subjects were involved in any form of nutritional supplementation that may have compromised the administration of the $NaHCO_{3-}$. Written consent was obtained from each subject after explanation of the purposes and associated risks of the study protocol. The experiment was conducted in compliance with the Declaration of Helsinki and was approved by the university ethics committee for human studies.

Procedures

Experimental protocol is illustrated in Figure 1. In each testing session, the subjects performed a standardized warm-up that involved 10 minutes of cycle ergometry (Lode Excalibur, Groningen, the Netherlands) at an intensity of 100 W. After 3 minutes of rest, the subjects performed a vertical jump test as an indicator of instantaneous power production. The vertical jump test involved two countermovement jumps (CMJs; Ergojump, Rome, Italy) interspersed by 1 minute of rest. Only the best jump from each subject was used in data analysis. This test was followed by a 3-minute rest period before the first of the three 30-second WTs (WT1, WT2, and WT3) was undertaken. All WTs were performed on the same ergometer as the warm-up cycle, with 30 minutes of passive recovery between each one. Subjects exercised against the standard resistive load (0.7 $N \cdot m \cdot kg^{-1}$ body mass). Peak and mean power (PP and MP, respectively), time to peak power (TPP), and fatigue index were downloaded to an online PC. Subjects were given verbal encouragement throughout the tests. Immediately after each WT, RPE and vertical jump height were obtained. At the end of each WT, the subjects were asked to stop for a few seconds and to indicate their ratings of overall RPE. RPE was measured with the Borg 15-point scale (1), which ranges from 6 (very, very light) to 20 (very, very heavy) and with a 10-point category ratio (28), which ranges from a low of 0 (nothing at all) to a high of 10 (very, very strong). Both scales were represented graphically on a paper on which the subjects were asked to mark the position corresponding to their perceived exertion. A written instruction was given before the test (28). A hyperemic earlobe blood sample for the analysis of [BLa] (Dr. Lange microphotometer, Berlin, Germany) was taken at 3 and 30 minutes after each WT. After the 30-minute blood sample, a value for perceived readiness (1–5 scale) (29) was also taken before the next WT. This scale determines the grade of recovery that subjects perceived, from 1 point (not recovered at all) to 5 points (completely recovered).

Before all trials subjects reported to the laboratory in a 3 hours' postabsorptive state. For the $NaHCO_{3-}$-ingestion trial, subjects ingested 1 L of solution containing $NaHCO_{3-}$ (0.3 $g \cdot kg^{-1}$ body mass). Sodium bicarbonate was dissolved in flavored mineral water, which has been demonstrated to elicit a state of metabolic alkalosis (8,10,22,24–26,33,39). The placebo trial consisted of an equimolar dose of sodium chloride (NaCL; 0.05 $g \cdot kg^{-1}$ body mass) added to the same flavored water to match solutions for taste in both PLC and $NaHCO_{3-}$ solutions. Both substances were ingested 90 minutes before exercise as recommended by different authors (17,24,25,34). Because of potential mild gastrointestinal discomfort associated with ingestion of $NaHCO_{3-}$, subjects were asked throughout the preexercise and exercise periods to rate their stomach comfort levels and their bowel urgency ratings (subjective feeling of urge to defecate). This was done using a 5-point scale, where 1 was equal to no discomfort/urge; 2, minor; 3, moderate; 4, severe; and 5 was equal to very severe discomfort/urge.

Statistical Analyses

Data are presented as means (± *SD*). A repeated-measures analysis of variance (ANOVA) was used to identify differences between treatments at each exercise period for all the dependent variables. Where a difference was found, this was investigated using a Tukey post hoc test. Intergroup differences (data obtained in all three exercise periods with each treatment) were analyzed using paired *t*-tests for related samples. Relationships between variables were determined using the Pearson correlation coefficient. Test-retest reliabilities for the experimental tests demonstrated intraclass correlations of $R \geq 0.95$. In all cases, the level of significance was set at $p \leq 0.05$.

RESULTS

Performance

Figure 2 shows the mean values of power output for the three WTs under $NaHCO_{3-}$ ingestion and placebo conditions. There were no significant differences in PP and TPP in any of the three WTs for the two treatments. Moreover, no significant differences were found in MP or fatigue index (Table 1). For each experimental condition, no significant differences were observed in all the performance variables analyzed between successive WTs (Table 1).

Positive correlations ($r = 0.40–0.87$, $p < 0.05$) were obtained between the PP attained under $NaHCO_{3-}$ and control trials (three WTs in each condition) and the gain in performance with alkalosis (defined by the difference in peak power during the WT between both $NaHCO_{3-}$ and placebo trials, expressed as percentages). The most representative

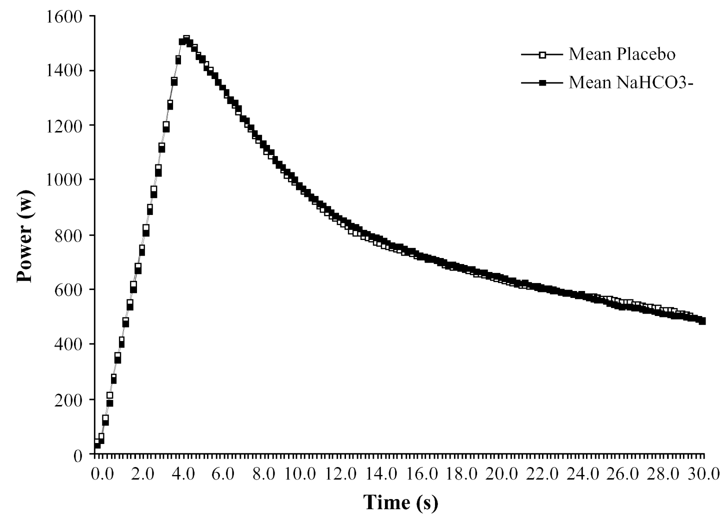

Figure 2. Mean values for the three Wingate tests after sodium bicarbonate ($NaHCO_{3-}$) and placebo (PLC) conditions.

case of these correlations is that obtained between the average value of PP attained during the three WTs performed in each condition and the average performance gain (average of gains in WT1, WT2, and WT3) (Figure 3).

A significant enhancement in CMJ performance after the WT1 was observed in the $NaHCO_{3-}$ trial in comparison with control (34.1 ± 1.3 vs. 36 ± 1.3 cm, $p = 0.027$). No significant differences were observed after WT2 and WT3, although performance tended to be better for the $NaHCO_{3-}$ condition (average of 1.44 cm of improvement, ~4%). CMJ performance after WT1, WT2, and WT3 was significantly decreased in comparison with CMJ performance at rest, with a similar pattern of CMJ performance in both trials. Moreover, CMJ performance after WT2 and WT3 was significantly decreased in comparison with CMJ after WT1. No significant differences were observed between CMJ performance after WT2 and WT3. A significant correlation ($r = 0.91$, $p \leq 0.01$) was observed between CMJ before WT1 and PP in WT1.

Blood Lactate

No significant differences were found for [BLa] at 30 minutes after each WT ($[BLa]_{30min}$) between both conditions. However, for [BLa] at 3 minutes after each WT ($[BLa]_{3min}$), a significant increase was observed in the $NaHCO_{3-}$ condition after WT2 ($p = 0.014$) and tendency to be greater after WT3 ($p = 0.07$) (Figure 4). For both placebo and $NaHCO_{3-}$ trials, $[BLa]_{3min}$ was significantly higher after WT2 when compared with WT1, but it was not different between WT2 and WT3 (Figure 4). A similar response was observed in $[BLa]_{30min}$ in the placebo condition. However, in the $NaHCO_{3-}$ condition, $[BLa]_{30min}$ was significantly increased after each successive WT.

Rating of Perceived Exertion and Readiness

No significant differences were found for RPE between trials for either RPE scale employed. The CR10 scale demonstrated a tendency for differences between the two conditions (WT1, $p = 0.06$; WT3, $p = 0.09$). No correlations were found between values from either RPE scale and [BLa] (Figure 5).

Significant differences were observed between perceived readiness (1–5 scale) for the WT2 and WT3 ($p = 0.023$ and $p = 0.019$, respectively), in favor of the $NaHCO_{3-}$ condition (Figure 5). At the end of the experimental protocol, cyclists were asked to rate which of the two experimental sessions felt the best for them when considering the tests performed to be a competition. Eight of the nine cyclists felt that their best performance occurred during the $NaHCO_{3-}$ condition, with

Table 1. Performance in each Wingate test (WT1, WT2, and WT3) under $NaHCO_{3-}$ingestion and placebo conditions.

		WT1	WT2	WT3
PP (W)	$NaHCO_{3-}$	1607 (310)	1504 (304)	1513 (249)
	PLC	1599 (265)	1535 (242)	1514 (195)
TPP (s)	$NaHCO_{3-}$	4.5 (0.3)	4.3 (0.2)	4.5 (0.3)
	PLC	4.3 (0.2)	4.4 (0.2)	4.4 (0.1)
MP (W)	$NaHCO_{3-}$	788 (98)	787 (96)	780 (93)
	PLC	807 (92)	786 (99)	781 (90)
Fatigue index ($W \cdot s^{-1}$)	$NaHCO_{3-}$	43.9 (10.9)	39.7 (10.0)	40.8 (7.6)
	PLC	44.8 (7.9)	40.5 (8.2)	40.5 (6.8)

Values are expressed as means (± *SD*). MP = mean power; $NaHCO_{3-}$= sodium bicarbonate; PLC = placebo; PP = peak power; TPP = time to peak power.

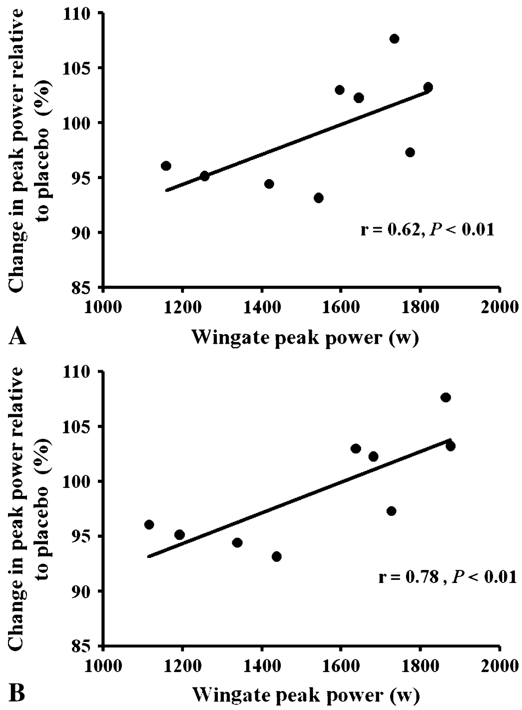

Figure 3. Relationship between the average value of peak power attained during the three Wingate tests performed in control (A) and sodium bicarbonate (B) trials and the performance gain. The performance gain is defined as the average of the relative changes in PP (in sodium bicarbonate trial respect to placebo) attained during Wingate tests 1, 2, and 3.

one cyclist reporting the same performance perceptions for both trials.

Discussion

The main findings of the present study were that $NaHCO_{3-}$ ingestion 1) had no effect on performance and RPE during a series of three WTs interspersed by 30 minutes of recovery simulating a BMX qualification series and 2) improved significantly ratings of perceived readiness before WT2 and WT3.

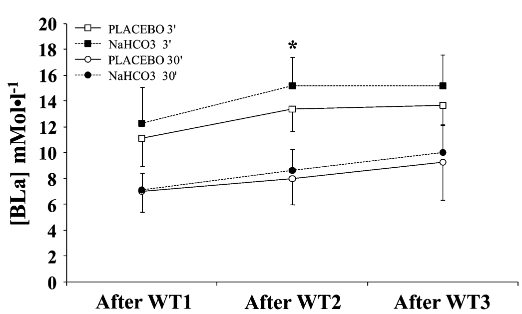

Figure 4. Blood lactate concentration [BLa] at 3 and 30 minutes after each Wingate test (WT1, WT2, and WT3) after sodium bicarbonate ($NaHCO_{3-}$) and placebo (PLC) ingestion. *Significant at $p \leq 0.05$ level from placebo trial.

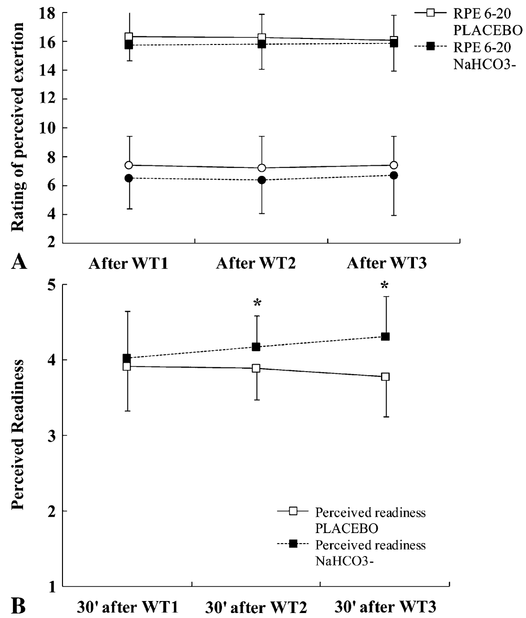

Figure 5. Rating of perceived exertion (RPE) in 6–20 and CR10 scales after each test (Wingate tests [WTs] 1, 2, and 3, respectively) (A) and perceived readiness response before each WT (B) after sodium bicarbonate ($NaHCO_{3-}$) and placebo (PLC) conditions. *Significant at $p \leq 0.05$ level from placebo trial.

The absence of any ergogenic effect in the first WT performed in the protocol is in agreement with those studies that have analyzed the effect of $NaHCO_{3-}$ administration before one WT (7,23,24,30). Only Inbar et al. (13) and Douroudos et al. (7) observed significant increases in WT mean power subsequent to bicarbonate loading, but they showed no effects on other WT parameters measured. Douroudos et al. (7) compared three treatment conditions (PLC, 0.3 $g \cdot kg^{-1}$ body mass, and 0.5 $g \cdot kg^{-1}$ body mass taken during 5 days) and suggest that the improvement in performance depends on the doses used, as just the greater amount of $NaHCO_{3-}$ was be clearly effective. However, this research used a Monark 834E ergometer to measure WT performance, which has been reported not to provide a correct calculation of power because of incomplete load transmission to the flywheel (19). In contrast to the results obtained by Douroudos et al., McNaughton (24), testing the effects of five different doses of $NaHCO_{3-}$ (from 0.1 to 0.5 $g \cdot kg^{-1}$ body mass), reported no differences in 60-second maximal cycling performance and venous blood pH when increasing the dose to more than 0.3 $g \cdot kg^{-1}$ body mass. Moreover, the highest value of cycling work and peak power were achieved with the dose of 0.3 g·kg^{-1} body mass. For the present study, we chose a dose of 0.3 g·kg^{-1} body mass dissolved in 1 L of flavored mineral water and ingested 90 minutes before the first WT. Although an important limitation of the present study was that blood pH and [HCO_{3-}] values were not monitored, the protocol selected has been extensively analyzed previously (17,22,24,25,33, 34,40) and proposed by several authors (10,17,40) as the most appropriate to obtain a blood alkalosis in humans without side effects (i.e., gastrointestinal distress). In this regard, an $NaHCO_{3-}$ intake of 0.3 g·kg^{-1} body mass at rest produced an increase of approximately 4–5 mmol·L^{-1} of the [HCO_{3-}] and 0.03–0.06 pH units in venous plasma for approximately 3 hours after ingestion (8,24), with a peak in pH and [HCO_{3-}] at 100–120 minutes. Thus, the lack in WT performance observed in the present study may consequently not be attributable to the $NaHCO_{3-}$-administration protocol used.

In the present study, we selected elite sprint cyclists well familiarized with WT, and we hypothesized that in these subjects the effects of $NaHCO_{3-}$ ingestion over WT should be more significant than those published previously in sedentary subjects. It is known that sprinters have an increased ability to activate high-threshold motor units during maximal voluntary contractions (16) and a greater percentage of type II fibers in their muscles than endurance trained or untrained subjects (9). Fast-twitch fibers are characterized by a greater intramuscular acidosis during their activation (nearly fourfold difference in the maximum mechanical power output and the ATP hydrolysis rate) than slow-twitch fibers (44). Moreover, fast-twitch fibers are more susceptible to force depression with acidosis (3). On the contrary, one of the principal mechanisms proposed to explain why the induced blood alkalosis may enhance exercise performance is an improved H^+ efflux out of the muscle cell, thereby limiting the effects of the decreased pH_i (17,33,34,41), especially in the face of increasing metabolic demand (33,41). It is known that the fatiguing effects of a declining pH_i during exercise include allosteric inhibition of the rate-limiting enzymes phosphofructokinase and glycogen phosphorylase, decreased release of Ca^{2+} from the sarcoplasmatic reticulum, and a reduction in the number and force of muscle cross-bridge activations (17,37). In this sense, induced alkalosis has been shown to increase muscle phosphorylase, phosphofructokinase, and pyruvate dehydrogenase activities during high-intensity exercise, resulting in enhanced glycogen use with a concomitant increase in pyruvate production, increased intramuscular Lac^- accumulation, and enhanced Lac^- efflux from the activated fibers (10). Indeed, in the present study we found an enhanced [BLa] at 3 minutes after WT2 and WT3 in the $NaHCO_{3-}$ trial. However, the mechanisms responsible for the reduced muscle [H^+] during alkalosis are unclear. Proposed mechanisms include increased skeletal muscle Lac^-/H^+ cotransporter activity, increased Na^+/H^+ exchange, and/or an increased intracellular strong ion difference (33,40). An attenuated intracellular acidosis in alkalosis compared with a control condition has been found during 5 minutes of dynamic, high-intensity handgrip exercise (27), 9 minutes and until to volitional fatigue (8) of moderate to heavy-intensity wrist-flexion exercise, and after a 1-hour cycling time trial (33). On the basis of these results, an enhanced ergogenic benefit from induced blood alkalosis should be expected in subjects with higher percentages of fast-twitch fibers in their muscles during activities in which those fibers should be recruited. However, the results found in the present study did not support our hypothesis; instead, they are in agreement with previous studies that have suggested that when exercise protocols of short duration (30–40 seconds) are used, alkaline agents have minor or no effects on performance (7,12,23,24,26,30). Nevertheless, although we did not obtain a significant enhancement in WT performance in the whole group tested, it is important to point out that in our sample, the more powerful subjects got the greater the gains after alkalinizant ingestion (i.e., for subject 1, PP was 1833 vs. 1936 W in WT1, 1672 vs. 1847 W in WT2, and 1698 vs. 1814 W in WT3, comparing PLC and $NaHCO_{3-}$-ingestion conditions). In this regard, significant correlations between PP in both conditions and the gain in performance (W) after $NaHCO_{3-}$ ingestion ($r = 0.40$–0.87; $p < 0.01$) were obtained (see Figure 3). Further research is needed to find out whether subjects with greater percentages of fast-twitch fibers in their working muscles are better "responders" to induced blood alkalosis in high-intensity, short-term exercises (less than 1 minute).

In the present study, we did not perform arterial/venous blood sampling, measurements of leg blood flow, or muscle biopsy that would permit us to elucidate which mechanisms underlie the lack of WT improvement after $NaHCO_{3-}$ intake. On the basis of the literature reviewed, the failure of alkalosis to increase WT performance may be explained by an insufficient time during the exercise to allow a significant difference in H^+ ion efflux from the muscle fibers or an inability to generate a sufficient difference in H^+ ion gradient to produce a difference between trials (8,17,20,22,23,41). Both of these could result in insignificant differences in pH_i, in which case muscle performance would be expected to be similar (10,22). In apparent contrast with this possible explanation, recent studies have shown that induced intramuscular acidosis has limited effects on muscle contractile function at body temperatures (2,34) and may even exert a protective effect on excitability and performance (32). On the basis of these studies, Sostaric et al. (39) have proposed that the major beneficial effect of alkalosis on muscle performance might be the preservation of muscle membrane excitability by its integrated effects on K^+, Na^+, Cl^-, and Lac^- homeostasis. However, in this study pH_i was not monitored. Moreover, a number of in situ and in vivo ^{31}P-MRS studies have demonstrated a strong correlation between declines in pH_i and force production (8,31). A controversy exists about the role of intramuscular acidosis on muscle fatigue, especially when it is conceivable and not well studied that H^+ may interact with some other factors that change during intense exercise (as Na^+, Cl^-, or phosphate metabolites) to impair exercise performance (2,35). Similarly, a controversy exists regarding which mechanisms underlie the enhancement in human performance after $NaHCO_{3-}$ intake. Induction of a metabolic alkalosis may result in a complex series of metabolic effects such as lower intramuscular acidosis (8,33,40), changes in the activity of key regulatory enzymes and fuel use (8,10), or preservation of muscle cell membrane excitability (39) during exercise that may permit, under certain conditions of exercise intensity and duration, increases in muscle performance.

To the authors' knowledge, only one study has reported the effect of $NaHCO_{3-}$ ingestion on multiple WT. Parry-Billings and MacLaren (30) have proposed a series of three WTs interspersed by 6-minute recovery periods, showing a small, but not significant, effect on WT performance. This result is in agreement with those observed in the present study. However, because the present study simulated a BMX qualification series with 30 minutes of recovery between sprints, a direct comparison between studies is difficult. In this regard, Parry-Billings and MacLaren (30) have shown reduced mean and peak power outputs by successive WTs, whereas in the present study, mean and peak power outputs were not different during the three WTs. The lack of reduction in performance during the three consecutive WTs for both experimental conditions most likely reflects the longer recovery duration and consequent low levels of muscle fatigue at the beginning of WT2 and WT3. Hunter et al. (11) have shown that during a WT, larger motor unit recruitment strategy is not altered, suggesting that a 30-second period is ineffective for the feedback loop between intramuscular metabolism and the central nervous system to affect motor unit–recruitment strategies. It would be interesting to determine whether recovery duration alters the motor unit–recruitment strategy in successive sprints. In the present study, changes in CMJ performance immediately after each WT were taken as indirect indicators of the fatigue in the lower-body fast motor units. CMJ performance was significantly improved after WT1 and tended to be better after WT2 and WT3 (~4%) during the $NaHCO_{3-}$ condition in comparison with placebo. This improvement could reflect a faster recovery process after WT performance in those motor units that are recruited during both tests. However, the long recovery used between WTs in our protocol and in the study of Parry-Billings and MacLaren (30) may explain why this ergogenic benefit did not affect the performance during the subsequent WTs performed after the first WT in the $NaHCO_{3-}$ trial. Moreover, as previously reported for athletes (38), a strong correlation was found between CMJ performed at state and the PP generated during the WT. It may therefore be suggested that CMJ can be used as an indirect measure of maximal power output capacity in trained cyclists.

Acid-base balance, as measured by venous blood pH, [HCO_{3-}], and [BLa], has been shown by several studies to mediate the intensity of RPE during high-intensity as well as intermittent arm and leg exercise (36,42,43). Pedersen et al. (31) observed a positive effect of extracellular lactate on sarcolem excitability. Because effort perception may be related to the difference in the neural drive to activate muscles and the poor responses of these, an increase in excitability could improve the muscle response for the same neural drive. In the present study, RPE measured immediately after each WT was not affected by $NaHCO_{3-}$ ingestion. This result in is disagreement with those published previously (36,42,43) showing lower RPEs under alkalotic conditions relative to placebo. This discrepancy may be related to differences in the metabolic demands of the exercise task chosen. In the present study, we selected an activity performed at maximal intensity but, perhaps, with a short duration to generate important differences in pH_i (12,24). In this regard, Robertson et al. (36) have suggested that the mechanism underlying the relationship between acid-base balance and RPE during exercise may involve deleterious effects of accumulation of intracellular H^+ on force-generating capabilities of muscle as the muscle fatigues. On the other hand, improved ratings of perceived readiness were observed before WT2 and WT3 in the $NaHCO_{3-}$ condition. This result agrees with the data published previously by Swank and Robertson (43). These authors observed that during exercise recovery (3 × 5-minute exercise bouts at 90% $\dot{V}O_2$max, each separated by 10 minutes of recovery), perceived readiness was increased during the first 5 minutes of recovery in the buffer condition. However, in contrast with the study of Swank and Robertson (43), no correlations were found between [BLa] and the related grade of recovery perceived by the subjects.

Practical Applications

$NaHCO_{3-}$ ingestion had no effect on performance and RPE during a series of three WTs simulating a BMX qualification series. The short duration of the WT (30 seconds) and the long recovery time interspersed between efforts (30 minutes) may explain this lack of ergogenic benefit. However, $NaHCO_{3-}$ ingestion positively influenced subjects' recovery perceptions before WT2 and WT3. Moreover, significant correlations were found between PP during WTs and the gain in performance after $NaHCO_{3-}$ ingestion (Figure 3). On the basis of these results, we conclude that oral $NaHCO_{3-}$ administration is not a clearly effective method of improving performance in a BMX qualification series. However, taking in account the interindividual variability in the responses observed, we suggest that coaches should test the response of each subject to the oral $NaHCO_{3-}$ administration by individualized trials during training. Of particular importance with $NaHCO_{3-}$ ingestion are the potential gastrointestinal problems (17,34). However, these were not problematic in the present study, possibly because the athletes had used this substance on a number of previous occasions. This may have also resulted in adaptations to perceived exertion and readiness responses. A final important point to note is that eight of the nine cyclists reported that they felt they had made their best performance during the $NaHCO_{3-}$ condition, with just one cyclist reporting similar levels of performance in both trials. This supports previous studies reporting improved perceived exertion after the ingestion of $NaHCO_{3-}$.

Acknowledgements

The authors gratefully acknowledge the team manager of BMX Spanish National Team, Mr. Miguel Hernández-Pariente, for his interest and help, and Mr. Pablo Fernández-Gálvez (Sportlab, Granada, Spain) for the technical support.

References

1. Borg, G, Ljunggren, G, and Ceci, R. The increase of perceived exertion aches and pain in the legs, heart rate, and blood lactate during exercise on a bicycle ergometer. *Eur J Appl Physiol* 54: 343–349, 1985.
2. Cairns, SP. Lactic acid and exercise performance. Culprit or friend? *Sports Med* 36: 279–291, 2006.
3. Chase, PB and Kushmerick, MJ. Effects of pH on contraction of rabbit fast and slow skeletal muscle fibers. *Biophys J* 53: 935–946, 1988.
4. Chen, MJ, Fan, X, and Moe, ST. Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: a meta-analysis. *J Sports Sci* 20: 873–899, 2002.
5. Coombes, J and McNaughton, LR. Effects of bicarbonate ingestion on leg strength and power during isokinetic knee flexion and extension. *J Strength Cond Res* 7: 241–249, 1993.
6. Crowther, GJ, Jubrias, SA, Gronka, RK, and Conley, KE. A "functional biopsy" of muscle properties in sprinters and distance runners. *Med Sci Sports Exerc* 34: 1719–1724, 2002.
7. Douroudos, II, Fatouros, IG, Gourgoulis, V, Jamurtas, AZ, Tsitsios, T, Hatzinikilaou, A, Margonis, K, Mavromatidis, K, and Taxildaris, K. Dose-related effects of prolonged $NAHCO_3$ ingestion during high-intensity exercise. *Med Sci Sports Exerc* 38: 1746–1753, 2006.
8. Forbes, SC, Raymer, GH, Kowalchuk, JM, and Marsh, GD. $NAHCO_3$-induced alkalosis reduces the phosphocreatine slow component during heavy-intensity forearm exercise. *J Appl Physiol* 99: 1668–1675, 2005.
9. Gollnick, PD, Armstrong, RB, Saubert, CW, Piehl, K, and Saltin, B. Enzyme activity and fiber composition in skeletal muscle of untrained and trained men. *J Appl Physiol* 33: 312–319, 1972.
10. Hollidge-Horvat, MG, Parolin, ML, Wong, D, Jones, NL, and Heigenhauser, GJ. Effect of induced metabolic alkalosis on human skeletal muscle metabolism during exercise. *Am J Physiol* 278: E316–E329, 2000.
11. Hunter, AM, Clair Gibson, AST, Lambert, MI, Nobbs, L, and Noakes, TD. Effects of supramaximal exercise on the electromyographic signal. *Br J Sports Med* 37: 296–299, 2003.
12. Ibanez, J, Pullinen, T, Gorostiaga, E, Postigo, A, and Mero, A. Blood lactate and ammonia in short-term anaerobic work following induced alkalosis. *J Sports Med Phys Fitness* 35: 187–193, 1995.
13. Inbar, O, Rotstein, A, Jacobs, I, Kaiser, P, Klin, R, and Dotan, R. The effects of alkaline treatment on short-term maximal exercise. *J Sports Sci* 1: 95–104, 1983.
14. Johansen, L and Quistorff, B. 31P-MRS characterization of sprint and endurance trained athletes. Int J Sports Med 24: 183–189, 2003.
15. Kesl, LD and Engen, RL. Effects of $NAHCO_3$ loading on acid-base balance, lactate concentration, and performance in racing greyhounds. *J Appl Physiol* 85: 1037–1043, 1998.
16. Lattier, G, Millet, GY, Maffiuletti, N, Babault, N, and Lepers, R. Neuromuscular differences between endurance-trained, power-trained and sedentary subjects. *J Strength Cond Res* 17: 514–521, 2003.
17. Linderman, J and Fahey, TD. Sodium bicarbonate ingestion and exercise performance. An update. *Sports Med* 11: 71–77, 1991.
18. Lindinger, MI, Franklin, TW, Lands, LC, Pedersen, PK, Welsh, DG, and Heigenhauser, GJ. Role of skeletal muscle in plasma ion and acid-base regulation after $NAHCO_3$ and $KHCO_3$ loading in humans. *Am J Physiol* 276: R32–R43, 1999.
19. Macintosh, BR, Bryan, SN, Rishaug, P, and Norris, SR. Evaluation of the Monark Wingate ergometer by direct measurement of resistance and velocity. *Can J Appl Physiol* 6: 543–558, 2001.
20. Mainwood, GW and Worsley-Brown, P. The effects of extracellular pH and buffer concentration on the efflux of lactate from frog sartorius muscle. *J Physiol* 250: 1–22, 1975.
21. Mannion, AF, Jakeman, PM, and Willan, PL. Skeletal muscle buffer value, fibre type distribution and high intensity exercise performance in man. *Exp Physiol* 80: 89–101, 1995.
22. Marx, JO, Gordon, SE, Vos, NH, Nindl, BC, Gomez, AL, Volek, JS, Pedro, J, Ratamess, N, Newton, RU, French, DN, Rubin, MR, Häkkinen, K, Kraemer, WJ. Effect of alkalosis on plasma epinephrine responses to high intensity cycle exercise in humans. *Eur J Appl Physiol* 87: 72–77, 2002.
23. McCartney, N, Heigenhauser, GJ, and Jones, NL. Effects of pH on maximal power output and fatigue during short-term dynamic exercise. *J Appl Physiol* 55: 225–229, 1983.
24. McNaughton, LR. Sodium bicarbonate ingestion and its effects on anaerobic exercise durations. *J Sports Sci* 10: 425–435, 1992.
25. McNaughton, LR, Dalton, B, and Palmer, G. Sodium bicarbonate can be used as an ergogenic aid in high-intensity, competitive cycle ergometry of 1h duration. *Eur J Appl Physiol* 80: 64–69, 1999.
26. McNaughton, LR, Ford, S, and Newbold, C. Effect of sodium bicarbonate ingestion on high intensity exercise in moderately trained women. *J Strength Cond Res* 11: 98–102, 1997.
27. Nielsen, HB, Hein, L, Svendsen, LB, Secher, NH, and Quistorff, B. Bicarbonate attenuates intracellular acidosis. *Acta Anaesthesiol Scand* 46: 579–584, 2002.
28. Noble, BJ, Borg, G, Jacobs, G, Ruggero, C, and Kaiser, P. A category-ratio perceived exertion scale: relation to blood and muscle lactates and heart rate. *Med Sci Sports Exerc* 15: 523–528, 1983.
29. Nurmekivi, A, Karu, T, Pihl, E, Jurimae, T, and Lemberg, H. Blood lactate recovery and perceived readiness to start a new run in middle-distance runners during interval training. *Percept Mot Skills* 93: 397–404, 2001.
30. Parry-Billings, M and MacLaren, D. The effect of sodium bicarbonate and sodium citrate ingestion on anaerobic power during intermittent exercise. *Eur J Appl Physiol* 55: 524–529, 1986.
31. Pedersen, TH, De Paoli, F, and Nielsen, OB. Increased excitability of acidified skeletal muscle: role of chloride conductance. *J Gen Physiol* 125: 237–246, 2005.
32. Pedersen, TH, Nielsen, OB, Lamb, GD, and Stephenson, DG. Intracellular acidosis enhances the excitability of working muscle. *Science* 305: 1144–1147, 2004.
33. Raymer, GH, Marsh, GD, Kowalchuk, JM, and Thompson, RT. Metabolic effects of induced alkalosis during progressive forearm exercise to fatigue. *J Appl Physiol* 96: 2050–2056,2004.
34. Requena, B, Zabala, M, Padial, P, and Feriche, B. Sodium bicarbonate and sodium citrate: ergogenic aids? *J Strength Cond Res* 19: 213–224, 2005.

35. Robergs, RA, Ghiasvand, F, and Parker, D. Biochemestry of exercise-induced metabolic acidosis. *Am J Physiol Regul Integr Comp Physiol* 287: R502–R516, 2004.

36. Robertson, RJ, Falkek, JE, Drash, AL, Swank, AM, Metz, KF, Spungen, SA, and Leboeuf, JR. Effect of blood pH on peripheral and central signals of perceived exertion. *Med Sci Sports Exerc* 18: 114–122, 1986.

37. Roth, DA and Brooks, GA. Lactate and pyruvate transport is dominated by a pH gradient-sensitive carrier in rat skeletal muscle sarcolemmal vesicles. *Arch Biochem Biophys* 279: 386–394, 1990.

38. Sands, WA, McNeal, JR, Ochi, MT, Urbanek, TL, Jemni, M, and Stone, MH. Comparison of the Wingate and Bosco anaerobic tests. *J Strength Cond Res* 18: 810–815, 2004.

39. Sostaric, SM, Skinner, SL, Brown, MJ, Sangkabutra, T, Medved, I, Medley, T, Selig, SE, Fairweather, I, Rutar, D, and McKenna, MJ. Alkalosis increases muscle K+ release, but lowers plasma [K+] and delays fatigue during dynamic forearm exercise. *J Physiol* 570: 185–205, 2006.

40. Stephens, TJ, McKenna, MJ, Canny, BJ, Snow, RJ, and McConnel, GK. Effect of sodium bicarbonate on muscle metabolism during intense endurance cycling. *Med Sci Sports Exerc* 34: 614–621, 2002.

41. Street, D, Nielsen, JJ, Bangsbo, J, and Juel, C. Metabolic alkalosis reduces exercise-induced acidosis and potassium accumulation in human skeletal muscle interstitium. *J Physiol* 566: 481–489, 2005.

42. Swank, AM and Robertson, RJ. Effect of induced alkalosis on perception of exertion during intermittent exercise. *J Appl Physiol* 67: 1862–1867, 1989.

43. Swank, AM and Robertson, RJ. Effect of induced alkalosis on perception of exertion during exercise recovery. *J Strength Cond Res* 16: 491–499, 2002.

44. Zhen-He, H, Botinelli, R, Pellegrino, MA, Ferenczi, MA, and Reggiani, C. ATP consumption and efficiency of human single muscle fibers with different myosin isoform composition. *Biophys J* 79: 945–961, 2000.