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The Effects of NaHCO₃ and NaCl Loading on Hematocrit and High-Intensity Cycling Performance

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ABSTRACT

Driller M, Williams A, Howe S, Bellinger P, Fell J. The Effects of NaHCO₃ and NaCl Loading on Hematocrit and High-Intensity Cycling Performance. **JEPonline.** 2012:15(1):47-57. Inconsistent findings regarding the benefits of sodium bicarbonate (NaHCO₃) loading on exercise performance may be related to the use of sodium chloride (NaCl) as placebo substances. It has been postulated that the sodium content of both substances may contribute to performance benefits. The purpose of this study was to compare NaHCO₃ and NaCl to a physically inert placebo by evaluating the effect of acute loading on high-intensity cycling performance. Eight well-trained cyclists (age = 24 ± 7 yrs; mass = 77 \pm 9 kg; VO₂ peak = 59.8 \pm 8.6 mL•kg⁻¹•min⁻¹) completed a 2-min performance test on a cycling ergometer after either NaHCO₃ loading (SB), NaCl loading (SC), or placebo loading (D) in a randomized, double-blind design. Blood samples were taken pre- and post-loading and pre- and post-performance test to analyze hematocrit levels. The SB trial produced significantly higher (P < 0.05) mean power (watts) in the 2-min test (514.9 \pm 49.7) when compared to the SC and D trials (504.3 \pm 51.0 and 498.7 \pm 50.6, respectively), with no significant difference between SC and D trials (P > 0.24). There were no significant differences in hematocrit levels at any timepoint between the 3 trials (P > 0.05). These findings indicate that NaHCO₃ loading produced significant performance enhancement when compared to both NaCl and a placebo substance.

Key Words: Sodium Bicarbonate, Plasma Volume, Buffer, Alkalosis

INTRODUCTION

Sodium bicarbonate (NaHCO₃) has become a popular ergogenic aid used by athletes involved primarily in short-duration, high-intensity sports (6,7,21,34). To date, there have been some inconsistent results regarding the effect of NaHCO₃ loading on sports performance and uncertainty as to the physiological mechanisms by which it is supposed to elicit an ergogenic benefit (6,21,24,30).

High turnover of skeletal muscle ATP during intense exercise is associated with increased production of hydrogen ions (H⁺) and in turn, a reduction in myoplasmic pH (12). The acidosis in the muscle caused by the increase in H⁺ concentration is thought to hinder muscle contractile processes and force production (9,29). Research has demonstrated that H⁺ efflux from the muscle cell is inhibited by extracellular acidosis (16) and enhanced by an increased extracellular buffer capacity (22). NaHCO₃ loading is thought to improve the built-in buffering mechanisms in the prevention of metabolic acidosis, assisting to maintain optimal pH levels during exercise and, therefore, enhancing muscle function and performance (24). Although the proposed theory as to how NaHCO₃ loading works seems logical, the exact mechanism behind which NaHCO₃ is thought to enhance athletic performance is difficult to investigate. Studies that have reported ergogenic properties of NaHCO₃ directly attributed these effects to ingestion of the bicarbonate (HCO₃), paying little attention to the sodium (Na⁺) content. However, Kozak-Collins et al. (19) suggested that a possible explanation for the studies that have shown no performance improvement after NaHCO₃ loading when compared to a placebo, may be attributed to the placebo itself providing some performance enhancement. More specifically, Kozak-Collins et al. (1994) stated that, if grouped according to control substance, the studies that used calcium carbonate or a small amount of sodium chloride (NaCl) found a benefit in performance with NaHCO₃ ingestion while studies using a placebo that contained higher Na⁺ content were inconclusive (19).

Many previous studies have used NaCl as a placebo or control substance to match the Na⁺ content in NaHCO₃, although very few have considered the potential effects of Na⁺ by providing an alternate control (1,19,28). Ingestion of Na⁺ is thought to cause changes in intravascular volume (19,31), and subsequently, enhance exercise performance (31,32). Mitchell et al. (28) observed that intravenous infusion of both NaHCO₃ and NaCl significantly improved cycling endurance in a 30-min time to fatigue test when compared to a control (no infusion), despite the fact that only NaHCO₃ prevented acidosis during exercise. It was concluded that this result was likely to be caused by an increased intravascular volume from the Na⁺ infusion which would result in better perfusion of exercising skeletal muscle. Hinchcliff et al. (15) reported that oral administration of both NaHCO₃ and NaCl increased peak speed and performance time in equines during progressive treadmill running, despite the fact that blood pH was significantly more acidic in the NaCl trial. Similarly, Kozak-Collins et al. (19) found no significant difference between equal oral doses of NaHCO₃ and NaCl with respect to the number of bouts completed during exhaustive leg ergometry, notwithstanding acid-base changes during the protocol. These findings suggest that NaCl may not be an adequate physiologically inert substance to use as a placebo, possibly because of the Na⁺ concentration. However, the lack of a control trial using another substance makes interpretation of these results difficult.

To our knowledge, there are no studies in the literature that have compared the oral ingestion of NaHCO₃ and NaCl to a physiologically-inert placebo substance in well-trained athletes. Indeed, Mitchell et al. (28) used intra-venous infusion of these substances in recreationally-trained subjects; however, this is not a common or practical approach, and is now prohibited in the sport setting where NaHCO₃ loading is often used. Therefore, the objective of the current study was to investigate the effect of both NaHCO₃ and NaCl (matched for Na⁺ content) on short-duration, high-intensity cycling performance when compared to a physiologically-inert placebo in well-trained athletes.

METHODS

Subjects

Eight well-trained male cyclists volunteered to take part in this study (mean \pm SD; age = 24 \pm 7 yrs; height = 181 \pm 9 cm; mass = 77 \pm 9 kg; VO₂ peak = 59.8 \pm 8.6 mL•kg⁻¹•min⁻¹). Cyclists were advised of the risks associated with the protocol and signed an informed consent form prior to any testing taking place. The study was approved by the Institutional Human Research Ethics Committee and complied with the Declaration of Helsinki.

Design

This study used a randomized, double-blind, cross-over design. All subjects performed four trials; the first of which was a familiarization trial. Then, 3 days after the familiarization session, the subjects undertook 3 experimental trials. Each trial was separated by 48 hrs and consisting of a 2-min performance test and blood sampling for measurement of hematocrit. The experimental trials were preceded in a randomized order by acute NaHCO₃ loading (SB), NaCl loading (SC), and placebo (dextrose monohydrate) loading (D). The time between trials (48 hrs) was used to provide an adequate wash-out period for the ingested supplements (27).

Methodology

The subjects were instructed to arrive at each of the testing sessions in a rested, hydrated, and fasted (4 hrs) state, and were told to avoid strenuous exercise on the day of each testing session. They were also asked to record a 24-hr diet and training diary leading up to the first testing session, and to replicate this diet and training before each of the subsequent testing sessions. Subjects were to abstain from caffeine ingestion in the 12 hrs prior to each test session. Throughout the study, performance tests were always conducted on the same ergometer at the same time of day (± 1 hr) in order to minimize biological variation.

All supplements were administered in an equal number of gelatin capsules in order to blind subjects and researchers and to minimize the risk of gastrointestinal upset from NaHCO₃ (8). In the SB trial, the subjects ingested a 0.3 g•kg⁻¹ body mass dose of NaHCO₃. The SC trial required the subjects to ingest a 0.2 g•kg⁻¹ body mass dose of NaCl (matched with SB for equimolar sodium content). The same numbers of capsules were consumed in the D trial. Dextrose monohydrate (0.1 g•kg⁻¹ body mass) was used as it is a relatively physiologically inert substance that would not be expected to influence exercise performance, especially at such a low dose. The acute loading methods used in the current study have shown to be the most effective way in achieving an optimal acid-base balance before high-intensity exercise, (13,26) without the associated side-effects (6,8).

Under each condition, the subjects were required to commence ingesting the capsules 120 min prior to their test time (taken in 5 equal doses over a 60-min period). Fluid consumption was controlled with subjects consuming a total of 10 mL•kg⁻¹ body mass of water during each loading period. Once the loading period had ceased, the subjects were not to consume any additional fluid. Following the acute loading, subjects were instructed to rest for 45 min until they underwent a standardized warm up, which was replicated before each trial. The warm up consisted of 3 set intensities relative to the subject's body mass (2.0, 2.5, 3.0 watts•kg⁻¹), each lasting 3 min, before completing 5 maximal 3-sec sprints, separated by 10-sec to complete the warm up. Subjects then had 1-min of passive rest before commencing the exercise task. The 2-min cycling trial (EX) was performed on an air-braked, front access cycle ergometer (Repco Cycle Company, Canberra). The ergometer was connected to a custom made Power Evaluation System (PESS Version 2.0, UTAS, Launceston, Australia) which measured the peak and average power (watts). Prior to the study, the cycle ergometer was dynamically calibrated using a protocol that has been described elsewhere (25).

During the EX, the cardiorespiratory-metabolic variables were measured using a two-way non-rebreathing mouthpiece system (Hans Rudolf, Kansas, USA) connected to a Parvo Medics TrueOne 2400 metabolic analyzer (Parvo Medics, Inc., Salt Lake City, UT). The analyzer was calibrated before each test using alpha gases of known concentration, according to the manufacturer's instructions. VO_2 peak was taken as the highest 15-sec VO_2 value recorded over the duration of the EX.

Finger-tip capillary blood samples were taken for all trials on 4 occasions: pre-loading (0 min), postloading (60 min), pre-EX (120 min) and post-EX (125 min). Pre-EX hematocrit measures were taken immediately following the warm up. Capillary tubes were then spun for 4 min at 10,000 remin⁻¹ in a micro-hematocrit centrifuge (Hawksley, London) and analyzed using a micro-hematocrit reader (Hawksley, London) in order to give a relative measure of plasma volume.

Statistical Analyses

All data were analyzed statistically using mixed methods linear regression for repeated measures (Random Effects Repeated Measures ANOVA) using STATA version 10 (StataCorp LP, College Station, TX). Where assumptions of linear regression were significantly violated, ordinal logistic regression was used. Where statistically significant differences were identified, post hoc testing was performed using Holms tests to locate the means that were different. Statistical significance was set at P < 0.05. A Microsoft Excel spreadsheet was also used to compute chances that the true effects of the intervention were substantial, when a value for the smallest worthwhile change was entered (2). The spreadsheet estimated the mean effects of each intervention and their 90% confidence intervals and provided meaningful inferences and the clinical/practical significance that SB and SC had on performance compared with the D trial. To determine the value for the smallest substantial/worthwhile change for each variable 0.2 x the standard deviation was used (17). Group statistics are shown as means \pm standard deviations unless otherwise indicated.

RESULTS

The SB trial was associated with a significant improvement in mean power (watts) during the 2-min performance trial (EX) when compared to the SC (P = 0.048) and D trials (P = 0.004) (514.9 \pm 49.7, 504.3 \pm 51.0 and 498.7 \pm 50.6 watts, respectively (Table 1). There was no statistically significant difference in mean power between the SC and D trials (P = 0.24). However, when using the magnitude-based inferential approach, the effect was unclear, and any benefit of SC when compared to D was small for mean power (17% likelihood SC being positive - Table 1), with 0% chance of a negative effect when compared to D. Using the same method of analysis, there was a 56%/44%/0% likelihood of SB producing a positive/trivial/negative result for mean power when compared to SC.

There was a trend towards differences in peak power between the 3 trials (P = 0.09) with SB producing an average peak power of 51.3 watts and 82.3 watts higher than both SC and D, respectively (Table 1). There was also a possible small effect on peak power in the SC trial when compared to the D trial (54% likelihood of a positive result). All 8 subjects produced a higher mean power in the SB trial when compared to the D trial, with 7 producing their best result in the SB trial (Figure 1). Five subjects produced a higher mean power in the SC trial when compared to the D trial (54% likelihood of a positive result).

There was no significant difference in VO₂ peak between any of the trials (Table 1: P > 0.05) or for hematocrit between trials at any time point (Figure 2). However, when analyzing with magnitude-based inferences, there was a small benefit to VO₂ peak in the SB group when compared to D (42%/56%/2% likelihood of a positive/trivial/negative result).

Table 1. Physiological and performance variables measured during EX for the 3 trials, including the likelihood of practically substantial differences between the SB and SC trials when compared to the D trial, and the comparison between the SB and SC trials.

Measured Variable	Trial Mean (90% CI)			P-	Practical likelihood of SB being positive/trivial/negative	Practical likelihood of SC being positi ve/trivial/negative	Practical likelihood of SB being positive/trivial/negative
	NaHCO₃ (SB)	NaCI (SC)	Dextrose (D)	value	(Compared to D)		(Compared to SC)
2-minute power watts	514.9 # ^ (486.0 – 543.8)	504.3 ^ (474.6 – 534.0)	498.7 (469.2 – 528.1)	.0005 ¹	93/7/0	17 / 83 / 0	56 / 44 / 0
Peak power watts	935.4 (853.9 – 1016.8)	884.1 (795.2 – 973.1)	853.1 (764.6 – 941.6)	.09 ¹	88/11/1	54 / 38 / 8	71 / 28 / 1
VO ₂ peak ml•kg ⁻¹ •min ⁻¹	59.1 (53.4 – 64.8)	57.0 (51.1 – 62.9)	57.6 (52.2 – 63.1)	.43 ²	42/56/2	0 / 99 / 1	59/39/2

¹ As identified by a parametric mixed methods linear regression for repeated measures. ²As identified by nonparametric ordinal logistic regression due to skewed distribution of residual values. [#]Significantly different to D (P < 0.05) ^ Significant difference between SB and SC (P < 0.05)



Figure 1. Individual percentage differences as identified by mean power output in the 2-min cycling performance trial when comparing both Sodium Bicarbonate (SB) and Sodium Chloride (SC) to the Placebo trial (D).



Figure 2. Hematocrit pre-loading, immediately post-loading, pre-EX (60 min post-loading) and post-EX. The figure demonstrates that there were no significant differences at any time-points between groups (P > 0.05). Error bars refer to ± the standard error of measurement.

DISCUSSION

Given the conflicting results concerning the effects of NaHCO₃ induced alkalosis on exercise performance (1,21) and the fact that benefits are often attributed to the buffering effects of the HCO₃⁻ and not necessarily the role of Na⁺ in the ingestion of NaHCO₃, the aim of this study was to examine the effects of NaHCO₃ and NaCl on hematocrit and performance in well-trained cyclists when compared to a placebo substance. The findings from the current study suggest that SB loading significantly enhanced mean 2-min cycling performance when compared to both SC and D trials. There were no significant differences between SC and D for mean 2-min cycling performance when using traditional statistics (P = 0.24). When using a magnitude-based inferential approach, as is often used when studying small but well-trained athletic populations (3), the results were largely unclear with a trivial (i.e., small) benefit to performance for SC when compared to D.

When analyzing our data using magnitude-based inferences, we found a 17%, 83%, and 0% likelihood of SC being positive, trivial or negative, respectively, on mean 2-min cycling performance when compared to D (Table 1). When using the same approach between SB and SC, we found a 56% positive and a 44% trivial likelihood of SB being more beneficial to performance with 0% likelihood that SB would be negative when compared to SC. Given these comparisons between SC and D, coupled with the 44% chance that the difference between SB and SC is trivial, there exists some evidence to suggest that the proton buffering effects of HCO₃ may not be the only mechanism in enhancing performance through NaHCO₃ loading. Similar results are also evidenced in peak power data, with a 54% likelihood of SC being positive when compared to D and just an 8% likelihood of the effect being negative on peak power during the performance test (Table 1). In an applied sport

setting, coaches of athletes would be likely to implement a strategy that has any positive likelihood on performance, coupled with a very low likelihood of any negative or harmful effects. Even when the likelihood of a positive result is largely trivial, if there is little or no likelihood of any harmful effects, the intervention may be worth considering.

The only other study that has compared these two substances with a placebo trial showed a significant benefit of both NaHCO₃ and NaCl when compared to their control, with no significant differences between the two experimental trials (P > 0.05). An important difference between the Mitchell et al. (28) study and the current study is that our exercise protocol was of higher intensity and shorter duration making it more likely that bicarbonate buffering would elicit positive performance benefits as was the case. In contrast, Mitchell et al. (28) used a time to fatigue test at ~80% of VO2 max, lasting ~30 min. Another potential reason for the difference in results may be due to the method of supplementation. Mitchell et al. (28) used intra-venous infusion of the supplements, which is now prohibited by the World Anti-Doping Authority as a method of administering supplements in sport. Furthermore, Mitchell et al. (28), infused NaHCO₃ and NaCl throughout the exercise task (lasting ~ 30 min), while in the placebo/control group, there was no infusion (using a dry cannula). Potentially, the infusion of both NaHCO₃ and NaCl during exercise may have enhanced thermoregulation through maintenance of plasma volume, allowing increased skin blood-flow and dissipation of heat (28). The study found greater sweat rates in the NaHCO₃ and NaCl groups when compared to the control, which supports this claim. Previous research has also suggested lower core temperatures during exercise with saline infusion when compared to no infusion (11). These factors may have ultimately contributed to an improvement in performance for both the NaHCO₃ and NaCl trials due to the increased availability of blood-flow and, therefore, oxygen delivery, to the exercising muscles. Given that we loaded our subjects through oral supplementation before exercise (and controlled fluid ingestion); we would not necessarily expect to find the same benefits related to thermoregulation, as evidenced by our finding that there were no differences in hematocrit between the SB, SC and D trials.

While there is little doubt that SB was a more effective ergogenic aid when compared to both SC and D, the results from the current study warrant further investigation using a larger sample size. Like the study by Mitchell et al. (28), we also performed our study on only 8 subjects. Unfortunately, as is often the case when conducting research studies with trained athletes, we were limited by a small sample size. It is possible that completing the study with more subjects would clarify the differences in these results and provide us with a better understanding on whether NaCl does exert some ergogenic benefit when compared to a placebo substance during short-duration, high intensity exercise, as the current evidence still remains unclear (4,30).

The results in the current study support previous research that suggests ingestion of NaHCO₃ can improve performance in high-intensity exercise ranging from 1 to 7 min (10,13,20,35). The findings from these studies have been attributed to an increased bicarbonate concentration and extracellular pH helping to facilitate H⁺ and lactate ion efflux from active muscles (5,16,18). It is thought that this mechanism improves muscle glycolytic ATP production and enhances the contractile capacity of working muscles (5,23). A possible explanation for the Na⁺ concentration contributing to the overall performance effect relates to shifts in intravascular volume and, perhaps, improved oxygen delivery. It has also been proposed that the Na⁺ might have an effect on the intracellular (intra-muscular) H⁺ concentration - the site where acidosis would be expected to limit exercise performance (14). Sutton et al. (33) demonstrated that acidosis inhibits both glycolysis and the efflux of lactate from the muscle. A possible indirect way in which Na⁺ could have affected muscle pH is by improving perfusion of the muscle and thus, providing enhanced oxygen delivery and metabolite removal. Improved perfusion of the muscle can be achieved through acute plasma volume expansion (19,28). However, although a

crude estimate of hemoconcentration, there were no significant differences in hematocrit from the blood samples obtained at all time-points between the 3 trials. Post-EX, hematocrit increased in all groups with no significant difference between groups, which is likely to be associated with diaphoresis and fluid shifts within the body's compartments (32).

CONCLUSIONS

This study has added to existing research into NaHCO₃ ingestion and its effects on performance, demonstrating a 3.2% improvement in mean 2-min cycling power output following NaHCO₃ loading when compared to a placebo trial in well-trained cyclists. NaHCO₃ also contributed to a 9.6% improvement in peak power when compared to the placebo. The practical application of these results could transfer to any sports where a similar time-frame and intensity is required (e.g., various track cycling, swimming, and running events). Although not measured in the current study, the mechanisms by which NaHCO₃ loading was likely to improve performance can be attributed to its influence on the muscle buffering capacity, assisting in preventing metabolic acidosis and, therefore, enhancing muscle contraction during exercise. While we did not find NaCl to significantly improve performance similar to NaHCO₃ loading on exercise performance, warrants future research. Further investigation regarding the exact mechanisms behind both Na⁺ and HCO₃ loading for exercise, implementing larger sample sizes of well-trained athletes might provide more insight as to how they may exhibit ergogenic properties for athletic performance.

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