Impact of Sodium Bicarbonate on Blood Lactate and Psychometric Dimensions of Fatigue

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Abstract

Background

The purpose of this study was to assess the impact of sodium bicarbonate (NaHCO_3) on blood lactate (BLa) and psychometric dimensions of fatigue in response to exercise.

Methods

Twelve recreationally active subjects (age 22.25 ± 2.70 years) performed three (one control and two supplemented) sessions of a 20-minute progressive exercise routine. Subjects completed the control condition during session one, and in the two subsequent sessions, subjects were randomly provided a beverage with either a $0.15\text{g}\cdot\text{kg}^{-1}$ body weight NaHCO_3 or a placebo of $0.30\text{g}\cdot\text{kg}^{-1}$ body weight calcium carbonate (CaCO_3) in a double-blind manner. Measurements of BLa, heart rate (HR), state anxiety (SAI), rating of perceived exertion (RPE), and perceived mood states (POMS) were measured prior to and during the exercise protocol, and then immediately post-exercise.

Results

BLa levels were significantly different [$F_{(8,88)} = 2.04, p < .05$] between the three conditions. Further, BLa [$F_{(4,44)} = 41.25, p < .05$], HR [$F_{(4,32)} = 182.16, p < .05$], and RPE [$F_{(4,44)} = 140.13, p < .05$] increased significantly as exercise progressed, with BLa [$F_{(2,22)} = 5.55, p < .05$] and RPE [$F_{(2,22)} = 4.09, p < .05$] changing differently between conditions. SAI responses showed no change from pre-to post-measures, but a significant difference was seen between the conditions [$F_{(2,22)} = 3.84, p = .05$], with differences between the placebo and NaHCO_3 , but not the control. Only the POMS subscale of vigor was different between conditions [$F_{(2,22)} = 7.69, p = .003$], while the subscales of tension [$F_{(1,11)} = 6.59, p = .03$], anger [$F_{(1,11)} = 9.81, p = .01$], and confusion [$F_{(1,11)} = 7.21, p = .02$] changed across time.

Conclusions

Both BLa and RPE were greatest in the control condition compared to the placebo and NaHCO_3 conditions, with no differences being seen between the control and NaHCO_3 conditions for RPE, and between the placebo and NaHCO_3 conditions for BLa. Using either NaHCO_3 or CaCO_3 appears to provide benefits by blunting BLa production during progressively intensive exercise, but differences in psychometric values suggest that other psychophysiological factors may impact perceptions of effort.

Background

The growth of competitive sports continues to broaden the demand for optimal training programs and potential ergogenic products. Though there are many philosophies regarding training techniques and programming, the ability to generate powerful and explosive movements is required in almost all competitive sports. Basketball, football, soccer, volleyball, and tennis, among others, require powerful and explosive activities to be performed in a metabolically fatigued state due to the length and repetitive nature of each individual sporting event(1).

Lactate production increases as exercise intensity increases(2) and is largely dependent on muscle fiber type(3). Lactate can be cleared via its use as an energy source, but when energy demand exceeds glycolytic capacity and lactate production exceeds clearance, lactate will accumulate(4).

The ability to metabolize or tolerate lactate and simultaneously produce power can be an invaluable element of performance. Increases in blood lactate (BLa) levels have also been shown to strongly correlate with marked increases in rating of perceived exertion (RPE)(5, 6), anxiety(6), and negative affect(7)). This suggests that BLa may contribute not only to peripheral fatigue (localized to the working musculature) but may also contribute to central (perceptually-based) fatigue(8). However, the use of sodium bicarbonate (NaHCO_3) has been demonstrated to improve performance(9, 10), decrease BLa levels(11, 12), and reduce RPE values(12) in response to exercise. NaHCO_3 has demonstrated the greatest benefits to performance in high-intensity tasks that last between 30 s and 10 min(13, 14).

Generally, decreases in hydrogen (H^+) ion concentration(15) have been seen using NaHCO_3 doses of at least $0.3\text{g}\cdot\text{kg}^{-1}$ body mass(10, 16–18); however, the volume of NaHCO_3 relative to this recommended dosage amount is unlikely to become a commonly used ergogenic supplement due to the potential for gastrointestinal (GI) distress(14, 15). Many athletes would be greatly inconvenienced with any symptoms of GI distress during competition.

Many of the studies utilizing higher doses of NaHCO_3 involve either supra-maximal(19, 20) or prolonged intermittent(21–23) workloads, but the impacts of lower doses of NaHCO_3 have not been examined at lesser, but progressively increasing intensities of exercise. Therefore, the purpose of this study was to examine the effects of a reduced dose of NaHCO_3 ($0.15\text{g}\cdot\text{kg}^{-1}$ body weight) on BLa responses and perceptions of fatigue during an increasingly intense bout of exercise. It was hypothesized that BLa, RPE, SAI, and affective measures would be lower when receiving NaHCO_3 supplementation taken 45 minutes prior to exercise compared to a placebo ($0.30\text{g}\cdot\text{kg}^{-1}$ CaCO_3) or control (no ergogenic supplement) condition.

Methods

Participants

Sixteen active (self-reported > 240 min per week of moderate-to-vigorous exercise) subjects volunteered for this study. Twelve participants including seven male and five female subjects, completed the study. Descriptive data of the participants is detailed in Table 1. Of the sixteen volunteers, one was disqualified due to exclusionary prescription medication being introduced after the commencement of the study, one had obligations that would not allow attendance at scheduled testing appointments, and two were no-shows for their scheduled testing times. All procedures were approved by the University Institutional Review Board and Institutional Biosafety Committee and participants provided written informed consent during the first session of data collection procedures.

Table 1
Physical characteristics of the participants (mean ± SD).

	Overall (N = 12)
<i>Age (y)</i>	22.3 ± 2.7
<i>Height (cm)</i>	169.3 ± 12.52
<i>Weight (kg)</i>	72.3 ± 13.9
<i>Body Fat %</i>	20.0 ± 7.36

Procedures

For session 1, subjects reported to the testing laboratory to initiate the testing procedure. After signing an informed consent, participants completed a health history questionnaire (HHQ) and physical activity questionnaire (PAQ). Participants who reported cardiometabolic diseases or musculoskeletal diseases were excluded, as well as individuals who reported having any musculoskeletal injury within the 6-month period prior to the study. Additionally, participants who self-reported using ergogenic supplements or prescribed medication impacting cardiometabolic function were also excluded from the study.

Upon completion and review of the HHQ and PAQ, participant’s height, weight, and body composition measurements were obtained via standard techniques. Height was obtained using a stadiometer (SECA model 769, Hamburg, Germany) and weight and body composition were collected via bioelectrical impedance analysis (InBody 720; Seoul, South Korea), according to manufacturer’s directions.

For session 2, 3, and 4, subjects were instructed to report to the testing laboratory for each session. Participants were tested in pairs in order to assist in maintaining the cadence of the exercise routine and to provide an additive motivation(24, 25). Subjects were instructed to arrive in an 8-hour fasted state, and this status was confirmed upon arrival. Testing protocols commenced once both subjects were present in the lab and were verified for participation.

Upon arrival at the lab the participants were asked to complete a State Anxiety Inventory (SAI)(26) and the Profile of Mood States (POMS)(27) questionnaires and were then provided with either the control (flavored water), placebo (CaCO_3 and flavoring), or NaHCO_3 supplement (and flavoring) beverage. All three beverages consisted of 296 ml of water and 2 ml of a liquid flavoring compound containing water, malic acid, propylene glycol, citric acid, sucralose, acesulfame potassium, potassium citrate, red 40, and potassium sorbate, with the placebo beverage also containing $0.30\text{g}\cdot\text{kg}^{-1}$ body weight of CaCO_3 , and the experimental beverage containing $0.15\text{g}\cdot\text{kg}^{-1}$ body weight NaHCO_3 .

Testing session 2 (control, flavored water) occurred first for all subjects, with sessions 3 and 4 being randomized for the placebo (CaCO_3 and flavoring), or NaHCO_3 (and flavoring) supplement beverage amongst participants using double-blinded methods. Participants were allowed five-minutes within which to complete drinking the beverage, and all subjects in the study were able to comply with this requirement.

After ingesting the designated beverage for the test day, participants were asked to sit quietly for 35-minutes before they were escorted to the testing area and reminded of the exercise protocol. Measures of heart rate (HR), BLa, and RPE were collected immediately prior to commencement of the exercise protocol (0 min), and again at 5 min, 10 min, and 15 min during exercise, and immediately upon cessation of exercise (20 min) for a total of 5 measurements during each protocol (see Fig. 1). All measures were collected near simultaneously, with each participant having a researcher dedicated to their respective data collection. Timing was controlled using a Macromedia Authorware (v.5) program written specifically for the protocol.

Once the pre-exercise measurements (HR, BLa, RPE) were obtained for both participants, the subjects were instructed to begin the exercise protocol. The exercise protocol began with step-ups onto a 30.5-cm platform using a metronome setting of 60 beeps per minute (BPM) to maintain the tempo. After two minutes and thirty seconds (2.5 min) subjects switched to jumping jacks in which their hands touched above their heads at one beep, and down to their sides for the next beep, repeating the movements until the 5-min mark. The participants followed this procedure until they were instructed to stop and sit down to obtain HR, BLa, and RPE measurements at the respective data collection time points (5 min, 10 min, and 15 min). The metronome setting increased after each stoppage for measurements to 70 bpm and 80 bpm, respectively. The step-ups and jumping-jack cycle continued until the 15-min measurement. Once the measurements were obtained at the 15-min timepoint, subjects were instructed to perform a modified burpee at a cadence of 90 bpm for the final 5-min. The exercise protocol ended at either at the conclusion of 20-min of cadenced exercise or when the subject could no longer keep pace with the metronome for greater than three repetitions. The final measurements were collected immediately upon the cessation of exercise.

To assess BLa, researchers utilized a single-use lancet device to puncture the skin just off the center of a fingertip pad utilizing aseptic techniques. The first flow of blood was wiped away with a cotton swab, and then approximately 5 μL (2mm) of blood was loaded on the lactate strip and immediately analyzed using

the Lactate Plus meter (Nova Biomedical, Waltham, MA). HR was collected using Polar heart rate monitor (model FT1, Polar Electro Oy, 2014) and RPE was measured using the 6–20 Borg Rating Scale(28) which was projected onto a wall in front of the participants.

Upon completion of the exercise protocol and collection of BL_a, HR, and RPE measures, participants were asked to complete the SAI and POMS once again and were also asked to evaluate the beverage they had ingested for taste and GI distress. After these tasks were completed, participants could depart the lab.

Subjects reported to the testing laboratory a week later to repeat the protocol for testing session 3 which was randomized for the placebo (CaCO₃ and flavoring) and NaHCO₃ (and flavoring) supplement beverage treatments. Session 4 took place another week later and all exercise protocols and testing protocols remained consistent, the only change between session 3 and 4 was the beverage provided.

Statistical Analysis

Data were analyzed using SPSS software for Windows (v26.0; Armonk, NY) and the level of significance set at $p \leq .05$. Repeated-measures analysis of variance (RMANOVA) were used to assess BL_a, HR, RPE, SAI, and POMS across time between and among the three testing sessions. Post hoc analyses were performed on significant main-effects for condition.

Results

All participants reached the last phase of exercise in the protocol in all three conditions, and there were no significant differences between total exercise times for all three conditions. The mean exercise duration ($\pm$ standard deviation [SD]) for each condition was 19.79 ± 0.52 min for the control session, 19.80 ± 0.58 min for the placebo session, and 19.10 ± 1.76 min for the NaHCO₃ condition. Participants reported no differences in taste between the beverages, although three participants reported GI issues (upset stomach) during the NaHCO₃ condition.

A 3 (condition) x 5 (time) RMANOVA demonstrated a significant condition by time interaction effect for BL_a [$F_{8,88} = 2.04, p \leq .05$], as well as main effects for condition [$F_{2,22} = 5.55, p < .05$] and for time [$F_{4,44} = 41.25, p < .05$]. Post hoc pairwise comparisons of BL_a revealed that the placebo and NaHCO₃ conditions were significantly different than the control condition ($d = 1.56, p \leq .05$), but not from each other (see Fig. 2).

The 3 x 5 RMANOVA analysis for HR values revealed no significant interaction effects for HR, nor was there a main effect for condition. A significant main effect for time was observed [$F_{4,32} = 182.16, p \leq .001$], with HR levels increasing across time in the same manner for all three conditions (see Fig. 3).

A 3 x 5 RMANOVA conducted for reported RPE values demonstrated no interaction effect, but significant main effects for time [$F_{4,44} = 140.13, p \leq .001$] and condition [$F_{2,22} = 4.09, p \leq .05$]. RPE increased across time in all three conditions, with reported RPE values also varying between the conditions (see Fig. 4).

Post-hoc pairwise comparisons revealed that RPE increased equally in the control and NaHCO₃ conditions, but that the placebo condition resulted in significantly lower scores compared to the control condition ($d = 1.02$, $p \leq .05$), but there were no differences between the placebo and NaHCO₃ values or the control and NaHCO₃ values.

A 3 (condition) x 3 (time) RMANOVA was performed to analyze SAI values. Results revealed no interaction effect or a main effect for time, but a significant main effect for condition ($F_{2,22} = 3.84$, $p = .05$) was demonstrated. Post-hoc analysis demonstrated no difference between the control condition when compared to either the placebo or NaHCO₃ condition, but that there was a significant difference ($d = 1.92$, $p = .03$) between the placebo and NaHCO₃ values (see Fig. 5).

A series of 3 (condition) x 2 (time) ANOVAs were performed on POMS scores for total mood disturbance (TMD), as well as the subscales of tension-anxiety, depression, anger-hostility, vigor, fatigue, and confusion (see Table 2). No significant interaction effects were demonstrated between conditions across time for any of the POMS measures.

A main effect for condition was demonstrated only for the POMS subscale of vigor ($F_{2,22} = 7.69$, $p = .003$), with post-hoc analyses demonstrating differences between the pre-exercise control condition and the NaHCO₃ ($t_{11} = 2.37$, $p = .04$) conditions, and the post-exercise control condition and the placebo condition ($t_{11} = 2.97$, $p = .01$) as well as the control and NaHCO₃ ($t_{11} = 3.41$, $p = .006$) conditions (see Fig. 6). Vigor was less in the NaHCO₃ condition compared to the control condition prior to exercise, and when the two supplemented exercises were compared to the control condition post-exercise, but the supplemented conditions were not different from each other, at either time point.

Main effects for time were revealed for the POMS subscales of tension ($F_{1,11} = 6.59$, $p = .03$), anger ($F_{1,11} = 9.81$, $p = .01$), and confusion ($F_{1,11} = 7.21$, $p = .02$). Post-hoc analyses revealed that tension subscores were significantly decreased in the NaHCO₃ ($t_{11} = 2.42$, $p = .03$) and placebo ($t_{11} = 2.45$, $p = .03$) conditions from pre- to post-exercise. Additionally, significant decreases across time for both anger ($t_{11} = 3.88$, $p = .003$) and confusion ($t_{11} = 3.08$, $p = .01$) scores were demonstrated only in the control condition.

Table 2
Pre- and post-exercise scores for psychometric variables (mean $\pm$ SE).

Psychometric Variable	Pre-Exercise Score	Post-Exercise Score
POMS - Total Mood Disturbance (TMD)	6.33 $\pm$ 4.92	0.67 $\pm$ 4.98
Control	3.25 $\pm$ 3.46	1.58 $\pm$ 4.30
Placebo	7.92 $\pm$ 4.25	0.08 $\pm$ 4.52
NaHCO ₃		
POMS – Tension-Anxiety	4.50 $\pm$ 1.36	3.08 $\pm$ 1.18
Control	3.42 $\pm$ 0.71	1.83 $\pm$ 0.89
Placebo	4.58 $\pm$ 0.83	2.42 $\pm$ 0.83
NaHCO ₃		
POMS – Depression	2.25 $\pm$ 0.91	1.58 $\pm$ 1.25
Control	1.67 $\pm$ 0.87	1.83 $\pm$ 1.14 [#]
Placebo	2.33 $\pm$ 1.27	1.33 $\pm$ 1.09 [#]
NaHCO ₃		
POMS – Anger	4.08 $\pm$ 1.03	1.33 $\pm$ 0.91 [#]
Control	2.45 $\pm$ 0.79	1.50 $\pm$ 0.97
Placebo	3.00 $\pm$ 1.15	0.75 $\pm$ 0.75
NaHCO ₃		
POMS – Fatigue	5.00 $\pm$ 0.95	4.83 $\pm$ 1.30
Control	3.75 $\pm$ 0.65	4.58 $\pm$ 1.23
Placebo	4.58 $\pm$ 1.18	3.67 $\pm$ 1.08
NaHCO ₃		
POMS – Confusion	3.17 $\pm$ 0.78	1.50 $\pm$ 0.92 [#]
Control	2.58 $\pm$ 0.81	1.42 $\pm$ 0.73
Placebo	2.75 $\pm$ 0.88	1.08 $\pm$ 0.73
NaHCO ₃		

Psychometric Variable	Pre-Exercise Score	Post-Exercise Score
POMS – Vigor	12.67 ± 1.02*	11.67 ± 1.39*
Control	10.58 ± 1.18	9.58 ± 1.43*
Placebo	9.33 ± 1.46*	9.17 ± 1.74*
NaHCO ₃		

Table notes

*Significant difference between the control and specified condition(s) ($p < .05$). #Significant difference across time within the specified condition ($p < .05$).

Discussion

The purpose of this study was to examine the effects NaHCO₃ supplementation on BLA and psychometric measures during high intensity bouts of exercise. The primary findings from this study reveal that there were significantly lower BLA measurements throughout a high intensity bout of exercise when ingesting either a NaHCO₃ or placebo supplementation compared to a control condition (no supplementation). This supports the hypothesis that the reduced dose of NaHCO₃ results in lower BLA measurements as compared to the control (no supplementation). In addition, significantly lower BLA measurements were also found with the placebo (CaCO₃) condition, which were lower than the NaHCO₃ supplement.

When subjects ingested the NaHCO₃ supplement, they had significantly lower BLA than the control (no supplement) condition. The buffering capabilities of NaHCO₃ have been demonstrated in previous studies(10, 17, 18, 29) using of at least 0.3g–kg⁻¹ body mass NaHCO₃ and this is reflected the results found in the current study. However, this study utilized a lower volume of NaHCO₃ (0.15g • kg⁻¹ body weight NaHCO₃) as an ergogenic supplement. Though performance benefits were not evaluated in the current study, a conclusion can be drawn that the lower dosage of NaHCO₃ may increase performance during progressively intensive activities within a limited time frame. Further, Robergs, et al.(30) demonstrated that by increasing buffering ability even slightly within the body (as in this study), could thus attenuate the decline in blood and muscle pH and potentially lead to improved performance.

No significant BLA differences were found between the NaHCO₃ and the placebo conditions. The lack of differences may be the result of the presence of a flavored liquid substance in the subjects' mouth as they ingested the supplement, as Gam, et al.(31) found significantly reduced levels of BLA in subjects using four different mouth rinses (quinine, plain water, glucose, control) prior to and following exercise. Further research would be warranted to determine if the reduced BLA were due to the NaHCO₃, or simply a physiological response to a liquid solution being introduced through the mouth.

There were no significant differences in HR between conditions, although HR did increase as the intensity and duration of the exercise increased. The similarity of the HR responses was expected, as it is known that HR will increase in response to escalations of exercise intensity. Also, the similarity of workloads between trials was established by the metronome cadence and the lack of differences in HR between conditions further suggested the intensity of the exercise was similar for participants in all three conditions.

Psychometric values in this study varied based upon either time or condition, but differences across time between conditions were not seen for any of the psychometric variables. RPE values increased across time in all three conditions but were significantly different in the placebo condition compared to the control and NaHCO₃ conditions. Increased RPE values across time in all three conditions suggested the participants perceived the exercise protocol to increase in the exertion required in each stage. However, variances in RPE scores may have been impacted by the three individuals who reported nausea as a result of ingesting the NaHCO₃, thus resulting in the significantly lower RPE scores seen in the placebo condition compared to the control and NaHCO₃ conditions. Even though no order effect was seen between the NaHCO₃ and placebo condition, the control condition was maintained as the initial condition for all participants to ensure participants were familiar with the exercise protocols prior to the experimental conditions, and thus the first exposure to the exercise protocol may have resulted in greater RPE scores when compared to the subsequent exercise bouts.

State anxiety scores were found to not be different between the control and the other two conditions, but a significant difference were seen between conditions for the placebo and NaHCO₃ scores, with the NaHCO₃ SAI values being greater than placebo values. This is an atypical result, as acute bouts of exercise have been shown to cause decreases in anxiety levels(32, 33). Potential reasons for greater state anxiety within the NaHCO₃ condition may be related to the reported nausea with the three participants in this condition, although NaHCO₃ has been suggested to result in an increase in the occurrence of panic attacks in clinical populations when infused endogenously(34). The finding of this study is unique, as no other studies have been found that have investigated the relationship between state anxiety and the use of NaHCO₃ during exercise. These results warrants further investigation in future studies to determine the effect of NaHCO₃ on the anxiety level of participants during exercise.

Participants POMS scores did not reveal any interaction effects for the POMS subscales, but vigor scores were significantly less in the NaHCO₃ condition prior to exercise but was not different after exercise. Again, the nausea caused by the NaHCO₃ may have impacted these feelings of vigor prior to exercise, but after the conclusion of the exercise, these feelings had resolved to an extent and the participants reported increased vigor values, which is a common result with exercise(35, 36). Additionally, similar to previous studies, POMS subscale scores of tension, anger, and confusion all decreased as a result of exercise(35–37).

Overall, psychometric values do not appear to be adversely impacted with the NaHCO_3 treatment, but neither do they enhance the mood of participants. Rather, anxiety levels seem to have increased in response to the side-effects NaHCO_3 has previously been established to elicit.

One limitation of this study may have been the differences in fitness levels among the subjects. While the subjects self-reported they were above average in their weekly exercise participation (e.g., performed aerobic and resistance training exercises 4–5 days per week for a minimum of 150 minutes per week), there was no testing of the subjects to determine an estimated cardiorespiratory fitness level, and this may have limited the ability of some participants to reach higher levels of intensity, therefore eliminating the maximum potentials of the NaHCO_3 supplement. Additionally, the subjects' motivation levels may have influenced their desire to keep up with the metronome cadence, which would limit the ability to reach a state of high-intensity exercise.

Results of this study indicate supplementation of a NaHCO_3 beverage 45 minutes prior to commencement of exercise lowered the BLA during high intensity exercise compared to no supplement at all, and this dose does not seem to change psychometric values when compared to a placebo or no supplement at all. Individuals desiring to maintain high levels of performance during periods of high intensity training or competition may benefit from a pre-exercise dose of $0.15\text{g}\cdot\text{kg}^{-1}$ body weight NaHCO_3 . Being able to incorporate a palatable NaHCO_3 supplement without the instances of GI distress into regular pre-exercise nutritional regimens may result in increasing performance results over time, which could be an asset to competitive athletes. Future research of NaHCO_3 should include more quantifiable performance measures to draw inferences between lower levels of BLA and performance. In addition, recruiting subjects of similar fitness levels may reduce the effects of varying fitness levels on RPE.

Conclusions

Supplementing with an acute dose ($0.15\text{g}\cdot\text{kg}^{-1}$ body weight) of NaHCO_3 approximately 45 minutes prior to commencement of exercise may result in decreased levels of BLA during bouts of high intensity training or competition. The reduced BLA could increase the ability to perform more effectively at a state of high intensity which could result in greater training adaptations as well as during competitive engagements.

Abbreviations

BLa	blood lactate
BPM	beeps per minute
CaCO ₃	calcium carbonate
GI	gastrointestinal
HHQ	health history questionnaire
HR	heart rate
NaHCO ₃	sodium bicarbonate
PAQ	physical activity questionnaire
POMS	Profile of Mood States
RMANOVA	repeated-measures analysis of variance
RPE	rating of perceived exertion
SAI	State Anxiety Inventory
SD	standard deviation
TMD	total mood disturbance

Declarations

Ethics Approval and Consent to Participate

All procedures were approved by the Texas A&M University Corpus Christi University Institutional Review Board (IRB #53-15) and Institutional Biosafety Committee (IBC #09-19) and participants provided written informed consent during the first session of data collection procedures.

Consent for Publication

Not applicable.

Availability of Data and Materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing Interests

The authors declare that they have no competing interests.

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Authors' Contributions

HEW and CG contributed to the study design and data collection. HEW, CG, and MDB all assisted in data analysis and interpretation. HEW, CG, and MDB all contributed to the construction of the manuscript. All authors read and approved the final manuscript.

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Not applicable

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Figures

Figure 1

Data collection and exercise time points for the research protocol. BLa = blood lactate; HR = heart rate; POMS = perception of mood states; RPE = rating of perceived exertion; SAI = state anxiety inventory.

Figure 2

Blood lactate (BLa) measurements across time upon condition. *Significant difference between the control condition compared to the placebo and NaHCO2 conditions ($p < .05$). #Significant increase in BLa across time in all three conditions ($p < .05$).

Figure 3

Heart rate (HR) responses across time for the three conditions. #Significant increase across time in all three conditions ($p < .05$).

Figure 4

Rating of perceived exertion (RPE) across time in all three conditions. *Significantly lower RPE values for the placebo condition compared to the control condition ($p < .05$). #Significant increases in RPE across time in all three conditions ($p < .05$).

Figure 5

State anxiety inventory (SAI) scores across time based upon condition. *Significant difference between the placebo and NaHCO₂ conditions ($p < .05$).