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Original article

Effects of sodium bicarbonate supplementation on physical performance of runners

Efeitos da suplementação de bicarbonato de sódio sobre a performance física de corredores de rua

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ABSTRACT

Introduction: Sodium bicarbonate (NaHCO3) supplementation has been shown to reduce metabolic acidosis, and to optimize performance in predominantly anaerobic exercises. However, its effects on aerobic exercise remain inconclusive. **Objective:** This study aimed to evaluate the effects of NaHCO3 supplementation on performance and metabolic acidosis of street runners. **Methods:** 14 runners were randomly assigned to receive either placebo (PLA = 7; maltodextrin, 2x5 gday-1 for 27 days, and a dose of 0.3 g/kg administered on the 28th day, 60 minutes before the performance test) or NaHCO3 (BIC = 7; maltodextrin, for 22 days; 2x5 gday-1 of $NaHCO_3$ for five days, and a maximum dose (0.3 g/kg) administered on the 28th day before the performance test. The exercise performance was assessed before (PRE) and after (POST) supplementation, through a test consisting of 25 minutes running at 85% of maximal heart rate, followed by running to exhaustion, at 110% of the speed obtained in incremental test. Metabolic acidosis was assessed by urinary anion gap at before and after the intervention. **Results:** The mean time to exhaustion was 93.6 ± 21.2 and 82.6 ± 18.2 in PRE, and 130.3 ± 35.2 and 92.8 ± 17.0 seconds in POST (BIC and PLA, respectively). At rest, urinary anion gap was positive in both groups, in PRE and POST. After exercise, the means in the PRE were -26,2 ± 8,2 and -26,1 ± 3,7, and POST -14,9 ± 14,6 and -27,7 ± 4,0 mEq/L (BIC and PLA respectively). There was a negative correlation (-0.78) between metabolic acidosis and time to exhaustion. **Conclusion:** The study showed that sodium bicarbonate supplementation promoted performance improvement and urinary anion gap alteration in tracking runners submitted to the exhaustion test.

Keywords: running; sodium bicarbonate; acidosis; dietary supplements.

RESUMO

Introdução: A suplementação com bicarbonato de sódio ($NaHCO_3$) tem demonstrado reduzir acidose metabólica e otimizar a *performance* em exercícios predominantemente anaeróbios; porém, seus efeitos sobre exercícios majoritariamente aeróbios são inconclusivos. **Objetivo:** Avaliar efeitos da suplementação de NaHCO3 sobre *performance* e acidose metabólica de corredores de rua. **Métodos:** 14 corredores foram randomicamente distribuídos em grupo placebo (PLA = 7; 2 doses de 5 g/dia por 27 dias, e uma dose de 0,3 g/kg no 28o dia, 60 minutos antes do teste de *performance*) ou NaHCO3 (BIC = 7; placebo durante 22 dias, e cinco dias de NaHCO3: 2 doses de 5 g/dia; no 28o dia, 0,3 g/kg, 60 minutos antes do teste. O teste de *performance* antes (PRE) e após (POS) a suplementação consistiu em 25 minutos de corrida a 85% da frequência cardíaca máxima, seguidos de teste de exaustão, a 110% da velocidade máxima atingida em teste incremental. Acidose metabólica foi avaliada por ânion gap urinário. **Resultados:** O tempo até exaustão foi 93,6 ± 21,2 e 82.6 ± 18.2 no PRE, e 130,3 ± 35,2 e 92,8 ± 17,0 seg no POS (BIC e PLA, respectivamente). Em repouso, o *anion gap* urinário foi positivo nos dois grupos, no PRE e POS; após exercício, as médias obtidas no PRE foram -26,2 ± 8,2 e -26,1 ± 3,7, e no POS, -14,9 ± 14,6 e -27,7 ± 4,0 mEq/L (BIC e PLA, respectivamente). Houve correlação negativa forte entre *performance* e acidose metabólica (r = 0,78; p = 0,01). **Conclusão:** O estudo mostrou que a suplementação de bicarbonato de sódio promoveu melhora na *performance* e alteração de *anion gap* urinário de corredores de rua submetidos à teste de exaustão.

Palavras-chave: corrida; bicarbonato de sódio; acidose metabólica; suplementação alimentar.

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Introduction

The number of runners has increased significantly in recent years, which has improved the number of running events in the world, especially those of shorter duration, such as the five to ten kilometers (5 km to 10 km). In the United States, the 5 km races took 1st place in the ranking in the years 2018 and 2019, reaching an amount of 29 thousand races [1]. In Brazil, the same trend is observed [2,3].

Runs of up to 10 km use around 80% of aerobic metabolism for energy supply, leaving 15% and 5% for lactic and alactic anaerobic metabolism, respectively [4]. Although the main reason for the search for 5 km races is to improve the quality of life [3], inevitably, practitioners started to worry about their performance in the tests, seeking to avoid fatigue, that is, a drop in motor performance induced by exercise, as well as feeling tired and weak [5].

Among the metabolic factors capable of causing a drop in performance, metabolic acidosis stands out, capable of inhibiting the glycolytic pathway activity and impairing several stages of the contractile process [6]. The increase in acidosis during exercise is related to the degradation process of the adenosine triphosphate (ATP) molecule, as well as to the use of the lactic glycolytic pathway [7]. Therefore, the ingestion of nutritional supplements has been studied to induce alkalosis as a way of increasing the chemical buffering capacity, that is, a form of protection for the organism against metabolic acidosis and, consequently, against the appearance of fatigue during exercise [8].

Sodium bicarbonate has become one of the most used supplements for this purpose, having the potential ability to prolong high performance and maintain optimal performance in various sports practices, including high-intensity running, and especially practices that demand high anaerobic metabolism [9-11].

Therefore, given the growing number of runners in Brazil and the scarcity of studies that evaluate the effects of supplementation with buffering agents on sports performance in events of this nature, the relevance of the present study is evident, whose objective is to evaluate the effects of sodium bicarbonate supplementation on physical performance and metabolic acidosis in runners.

Methods

Experimental design

The present study was carried out in a total of five visits. On visit 1, clarifications were made regarding the objectives and methods of the study so that the participants could sign the Free and Informed Consent Terms (ICF). On the second visit, anthropometric assessment, guidance for food records, and familiarization with the running test were performed. On the third visit, three days after the second visit, the Conconi test was performed. Two days later, the fourth visit was carried out, when the exhaustion test, urine collection, and delivery of the food record referring to the day before the test were performed. During 27 days, the participants were monitored daily by a messaging service application to collect information about compliance with training sessions, supplementation consumption, and the possible emergence of side effects. During the same period, training sessions were monitored through apps or sports watches with a global position system (GPS). On the fifth visit, the exhaustion test, urine collection, and delivery of the food record referring to the day before the test was performed (Figure 1).

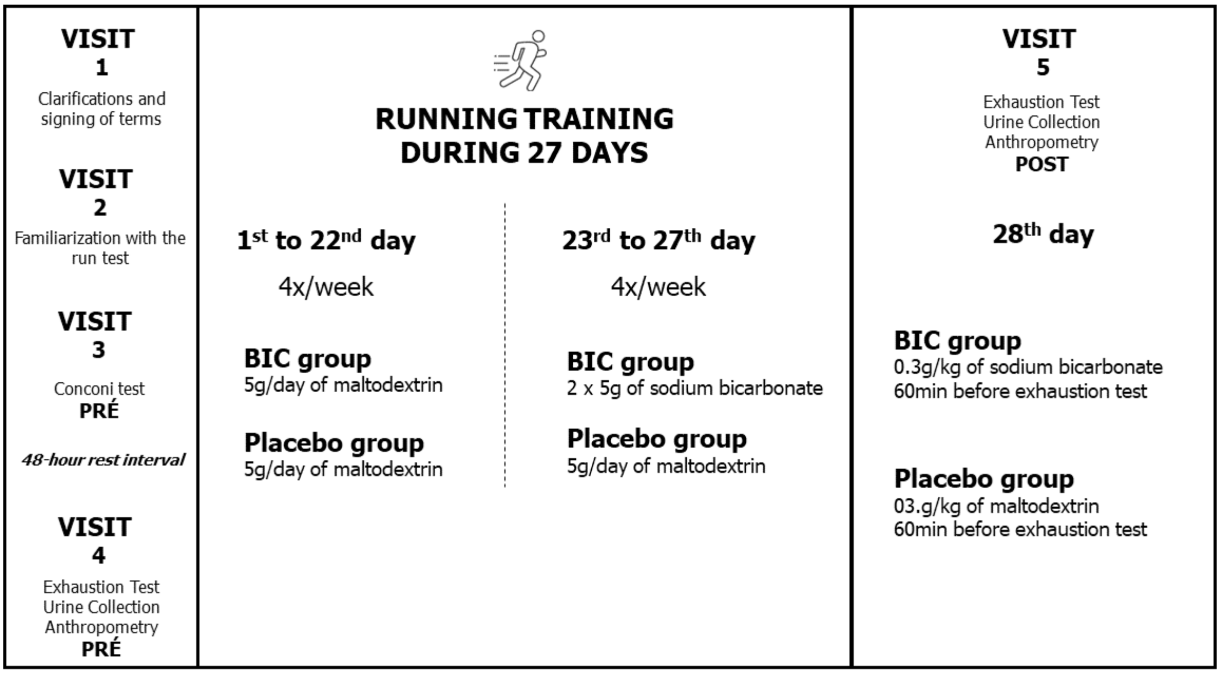

Figure 1 - Experimental study design

Sample

Fourteen male recreational runners were evaluated, enrolled in a sports advisory in Aracaju/SE, with a mean age of 35.3 ± 6.8 years; 75.7 ± 11.3 kg; 1.75 ± 0.1 m height; Body Mass Index of 24.7 ± 1.8 kg/m2 and percentage of fat mass of 15.5 ± 5.0%. Sampling was performed for convenience. To participate in the study, runners had to present: a) weekly training volume between 25 and 40 km, with an average pace per kilometer between 4.5 and 6.0 min/km in 5 km events; b) have experience of at least one year in 5km events; c) have a positive result in the Physical Activity Readiness Questionnaire [12] to detect possible contraindications for the practice of physical activity; d) sign the Term of Responsibility for the State of Health; e) not consuming ergogenic food supplements in the last 60 days.

As exclusion criteria, the following were considered: a) absence in 10% of training sessions; b) absence in running tests; c) consumption of other supplements based on nitrogen compounds; d) and the use of other resources considered ergogenic.

Supplementation protocol

The 14 participants were divided into two groups:

a) placebo group (PLA): due to the training periodization previously determined for this group of runners, the interval between assessments was set at 28 days; thus, the runners in this group received two doses of 5 g/day of unflavored maltodextrin for 27 days, and on the 28th day they consumed a single dose of 0.3 g/kg 60 minutes before the performance test;

b) sodium bicarbonate group (BIC): this group received a placebo in the first 22 days, the same as the PLA group; in the following five days (23rd to 27th days), the BIC group received two doses of 5 g/day of sodium bicarbonate; and on the 28th day, a single dose of 0.3 g/kg was administered 60 minutes before the performance test, according to the consensus of the International Olympic Committee about supplementation for high-performance athletes [10].

Table I - Characterization of the sample after division into groups at the beginning of the study - PRE supplementation (mean and standard deviation)

Variables	BIC (n = 7)	PLA (N = 7)	p-value
Age (years)	33.1 ± 7.9	37.0 ± 9.3	0.364
Body weight	77.0 ± 8.4	76.9 ± 9.0	0.663
Stature (cm)	1.76 ± 0.1	1.73 ± 4.0	0.551
BMI (kg/m2)	24.8 ± 2.8	24.6 ± 2.1	0.837
Fat mass (%)	16.0 ± 6.1	14.9 ± 6.2	0.732
Lean Mass (%)	84.0 ± 6.1	85.1 ± 6.1	0.732

BIC = Bicarbonate; PLA = Placebo; p-valu e= unpaired student's t-test

The supplements were packed in identical packages (sachets) and delivered weekly to the participants. Upon receiving the sachets, the participants received verbal and printed instructions on the ingestion procedures. The supplements were identified through codes unknown to both the researchers and the research subjects, thus characterizing a double-blind study.

Sports performance

To evaluate the sports performance, the exhaustion test on a treadmill was adopted. As a prerequisite for carrying out this test, it was necessary to know some individual variables of the runners, such as maximum heart rate (HRmax) and the running speed reached when the maximum heart rate was reached. Additionally, for the training prescription of the runners over the 28 days of supplementation, it was necessary to estimate the anaerobic threshold of each one. Therefore, to identify these three variables, a test adapted from Conconi [13] was adopted. It is worth mentioning that the anaerobic threshold was estimated through the heart rate deflection point.

a) *Conconi test adapted for the treadmill:* The incremental running protocol was applied on a treadmill (R-3500E, Riguetto, Brazil) with a 1.0% incline. The starting speed was 5.0 km/h, with speed increments of 1 km/h every 60s. The subjects walked in the first three phases (up to 7 km/h) and continued, however, running from 8 km/h until maximum voluntary exhaustion. It was defined as the subject's maximum velocity at half or the last full stage that the subject could sustain (in 30 or 60s). During recovery, subjects walked at 5 km/h for three minutes [14]. Heart rate monitors (Polar Electro, Kempele, Finland) were used to record heart rate (HR) continuously throughout the test.

b) *Exhaustion test:* After the 48-hour interval of the Conconi test, the exhaustion test protocol was applied on the treadmill with a 1.0% incline. The objective of the test was to simulate five km races, including their characteristic final sprint. Thus, the exhaustion test consisted of two stages:

First stage: 30 minutes, divided into a warm-up, in which the starting speed was 5.0 km/h, with increments between 1 to 2 km/h every 60s to reach, in the first five minutes, the speed corresponding to 85% of the HRmax obtained in the Conconi test; and continuous running of 25 minutes, maintaining the intensity of 85% of the HRmax of the runner. In addition to the HR, the intensity of the effort was monitored through the rating of perceived exertion (RPE) scale every 5 min [15].

Second stage: "All out" moment (exhaustion test) in which the subject ran at 110% of the maximum speed corresponding to the HRmax obtained in the Conconi test. There was no interval between one stage and another, the speed was gradually increased, and the timers started as soon as the target speed was reached. Heart rate was assessed before the tests, at the end of the warm-up, and after that, minute by minute until exhaustion, using a heart rate monitor.

Both performance tests were performed in a gym, and all runners had previous experience with treadmill running and running tests. The time of performance of each test was standardized by runner, remaining the same in the pre and post-supplementation periods.

Metabolic acidosis: As an indicator of metabolic acidosis, the urinary anion gap was adopted, which consists of the difference between cations and anions present in human urine. The values are determined from the urinary concentrations of chlorine, potassium and sodium, through the following equation: Urinary anion gap= $(Na^+ + K^+) - Cl^-$ [16].

For that, urine samples (minimum of 30mL) were collected in the performance tests in the following moments: a) rest (pre-test), b) exhaustion (post-test), in the PRE, and in the POST supplementation.

The samples were stored at 4ºC and transported on ice to a private laboratory, and the analyzes were performed by the selective electrode method. Negative urinary anion gap values were considered indicators of metabolic acidosis [17].

Body Composition: To calculate the percentage of fat, the Jackson and Pollock 7-fold equation for men aged 18 to 61 years was used, defined by: $[1.112 - 0.00043499 \times (\Sigma 7 \text{ folds}) + 0.00000055 \times (\Sigma 7 \text{ folds})^2 - 0.00028826 \times (\text{age})]$.

Assessment of side effects: the subjects were instructed to notify the research team of any symptoms, describing the affected body part, the moment when the effect appeared, and how long it took for it to appear and disappear.

Standards: food intake and training

Food intake: Individuals were given 24-hour food record sheets to be filled out the day before the PRE and POST supplementation tests, which should be returned and filled in according to the instructions initially offered. Participants were instructed to maintain the dietary pattern throughout the experiment, especially the day before and on the test days. To this end, the subjects received copies of the food records completed in the pre-supplementation period for trying to follow the initial dietary pattern. For the analysis of data from food records, the software Avanutri version 3.0 was used.

Training: During the 28-day interval between the first and second exhaustion tests, the participants followed training prescriptions planned by the responsible physical educator.

The training was performed four times a week (on alternate days), with equalization of the total distance to be covered. Subjects trained in parks and flat terrain racetracks. The total distances covered for each week were: week 1 = 30 km, week 2 = 33 km, week 3 = 36 km and week 4 = 30 km. The intensity of the runs was individually prescribed according to the anaerobic threshold obtained through the Conconi test. Two training sessions were prescribed using the continuous method and two sessions of the interval method. To accurately monitor the training, the subjects reported at the end of each session a race report obtained through applications or sports watches with a global position system (GPS).

During the investigation, runners were asked not to perform any "extra" physical exercise (not provided for in the prescription worksheet) to avoid possible interference in the final performance result.

Statistical treatment

The Shapiro-Wilk and Levene tests verified the normality and homogeneity of the data, respectively. Unpaired student's t-test was used to verify the difference between the groups for age and height. 2x2 ANOVA (group interaction [BIC x PLA] × time [moments]) followed by Tukey's post hoc tests determined the differences between the groups. All statistical procedures were performed using SPSS software - version 21.0. The significance adopted was $p \leq 0.05$. Pearson's linear correlation was used in the association between performance and urinary anion gap. The magnitude of the correlation followed the classification: r = 0.10 to 0.30 (weak), r = 0.40 to 0.60 (moderate) and r = 0.70 to 1.00 (strong), according to Dancey and Reidy [18].

Ethical aspects

The study was initiated after approval by the Research Ethics Committee of the Federal University of Sergipe (CAE 54233616.1.0000.5546, approval report number 1,486,265).

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Results

Table II shows that, in terms of performance in the exhaustion test, there was no difference between the BIC and PLA groups at the pre-supplementation moment; however, after this intervention, the performance of the BIC group was significantly superior to the PLA group, as well as superior to the BIC group itself at the pre-supplementation moment.

Also, in table II, it is noted that both groups entered into metabolic acidosis (negative anion gap) after exercise, both pre and post-supplementation, with differences ($p < 0.05$) between the moments of rest and post-exertion. However, there is a significant difference between the BIC and PLA groups at the time post-supplementation after the effort.

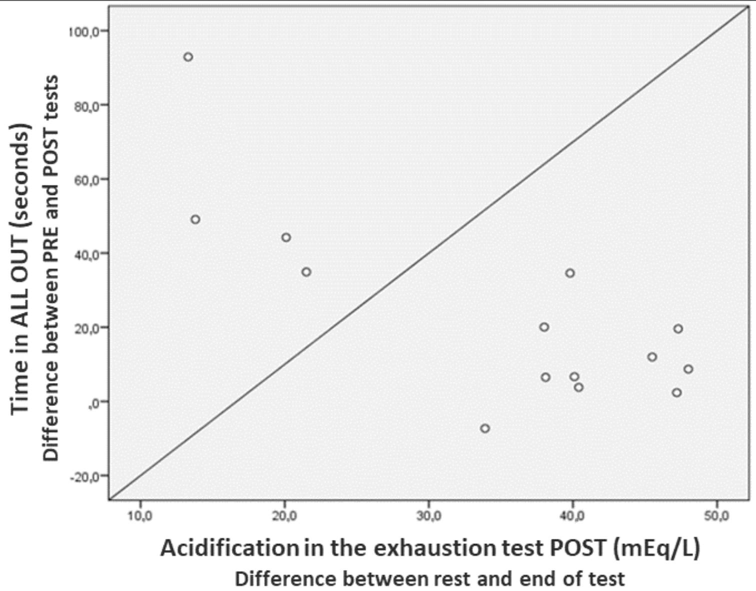
It is worth mentioning that the HRmax of the PLA group was significantly lower than the BIC group at the pre-supplementation moment. However, this difference did not appear after the intervention (Table II).

Table II - Physiological and physical performance variables of runners in the PRE and POST assessments (mean and standard deviation)

Variáveis	PRE M ± SD	POST M ± SD	p-value PRE-POST	p-value Group*time
HRmax (Bpm)				
BIC (n = 7)	203.4 ± 7.9	202.7 ± 8.8	0.473	0.027
PLA (N = 7)	188.6 ± 14.1a	190.3 ± 11.1	0.488	
All out time (s)				
BIC (n = 7)	93.6 ± 21.2	130.3 ± 35.2*	0.001	0.003
PLA (N = 7)	82.6 ± 18.2	92.8 ± 17.0b	0.274	
Anion gap - rest (mEq/L)				
BIC (n = 7)	13.0 ±2.4	13.0 ± 2.2	0.990	0.828
PLA (N = 7)	13.8 ± 2.5	14.0 ± 2.4	0.820	
Ânion gap – post-exertion (mEq/L)				
BIC (n = 7)	-26.2 ± 8.2#	-14.9 ± 14.6*#	0.001	0.001
PLA (N = 7)	-26.1 ± 3.7#	-27.7 ± 4.0#	0.535	

BIC = Bicarbonate; PLA = Placebo; HRmax = Maximum Heart Rate; Bpm = beats per minute; p-value = 2x2 ANOVA; Tukey's post hoc; PRE = pre-supplementation; POST = after supplementation. *Significant difference ($p \leq 0.05$) between PRE and POST assessments (Intragroup); #Significant difference ($p \leq 0.05$) between rest and post-exertion; [a]Significant difference ($p \leq 0.05$) between BIC and PLA in the PRE assessment; [b]Significant difference ($p \leq 0.05$) between BIC and PLA in the POST assessment

Figure 2 shows that the lower the metabolic acidosis (negative anion gap), the longer the time to exhaustion (performance) of runners, thus showing the strong and negative correlation between such variables ($r = -0.78$; $p = 0.01$).



Pearson's linear correlation; PRE = pre-supplementation; POST = after supplementation.
Figure 2 - Correlation between changes in performance in the exhaustion test and acidification (negative anion gap) of urine after exercise in the evaluation performed after supplementation with sodium bicarbonate or placebo (n = 14)

Body composition

There was no statistical difference in body weight between groups and time points (p = 0.867). Both groups showed a significant reduction in the percentage of fat mass (BIC reduction from 16.0 ± 6.1 to 14.2 ± 5.9; p = 0.034 and PLA reduction from 14.9 ± 6.2 to 12.5 ± 4.7; p = 0.004); however, with no difference between the groups (p = 0.266). Just as both groups had a significant increase in lean mass percentage (BIC change from 84.0 ± 6.1 to 85.8 ± 5.9%; p = 0.033 and PLA change from 85.1 ± 6.0 to 87.5 ± 4.6%; p = 0.004); however, with no difference between the groups (p = 0.671).

Caloric intake

There was no significant difference in energy consumption between groups and moments (BIC pre: 2689.46 ± 511.82 kcal and BIC post: 2350.33 ± 352.98 kcal; PLA pre 3308.33 ± 1255.48 kcal and PLA post: 2572 .51 ± 1057.69 kcal).

Side effects related to sodium bicarbonate

The presence of gastrointestinal discomforts, such as mild gastric pain and flatulence, was detected in 50% of the participants. Such effects were observed only on the day the maximum dose of sodium bicarbonate was offered, being triggered minutes after the end of the exhaustion test.

Discussion

The findings of the present study showed that only the sodium bicarbonate group showed a significant improvement in performance in the exhaustion test, as well as this group was able to alleviate the metabolic acidosis observed after physical exertion.

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It is believed that the positive effect of sodium bicarbonate supplementation on performance, observed in the present study, is a consequence of the better control of metabolic acidosis, suggested by the urinary anion gap. According to Kellum [17], in non-ill individuals, the urinary anion gap has a positive value or close to zero; however, in metabolic acidosis, there is a significant increase in ammonia (NH4+) and chloride (Cl-) excretion to maintain electro-neutrality, resulting in negative urinary anion gap values.

Thus, it is noted that before consuming the supplementation (PRE moment), both groups had anion gap averages considered normal, that is, positive or close to zero, while at rest, and negative averages after exercise, indicating that the exhaustion test provoked metabolic acidosis. After supplementation, sodium bicarbonate did not prevent but significantly ameliorated metabolic acidosis, which may have caused a difference in performance in the exhaustion test.

The hypothesis that the performance improvement observed in this study, after sodium bicarbonate supplementation, is due to better control of metabolic acidosis and can be reinforced by the strong and negative correlation between time to exhaustion and urinary anion gap at the time after supplementation, in agreement with Lancha Junior *et al.* [19], which emphasizes the buffering function of this supplement.

During high-intensity exercise, especially in the final sprint of running events, muscle work usually occurs above the anaerobic threshold, associated with a large production of lactic acid and, consequently, the release of H+ and carbon dioxide, which are accumulated in muscle and blood. In this situation, sodium bicarbonate will drain H+ ions from the muscle to the blood, decreasing muscle acidosis and providing an improvement in the athlete's performance [11].

It is worth mentioning that the exhaustion test adopted in the present study is characterized as high-intensity, simulating a final sprint of a race, and that, therefore, it is capable of generating a significantly high release of H+, which may benefit from a greater buffering capacity, as suggested by Grgic *et al.* [20]. It is worth mentioning that the use of the treadmill as a means of evaluating performance can be considered a limiting factor, as it is a group of runners. However, to alleviate this limitation, subjects were familiarized with the tests on the treadmill, as well as adapted to the slope that simulates running.

The RPE was used to monitor the possible interventions between the two moments of performance evaluation in the exhaustion test. There were no intrapersonal changes in RPE between the pre and post-supplementation moments, indicating that the runners started the all-out in the post-supplementation test under the same conditions of physical exhaustion that started in the pre-supplementation test, reproducing a similar demand, allowing the evaluation only the effect of supplementation.

The findings of the present investigation are in agreement with previously published results [21-25]. It was reported by Crivelaro [24], improvement in RPE in 53.3% and a reduction in fatigue index (FI) in 64.3% of 30 soccer players who received acute supplementation of 0.3 g/kg of sodium bicarbonate body weight, between 90 and 120 minutes before the tests, and who underwent sprints to simulate events arising from a match.

Another report shows that the use of 0.3g/kg of body weight of sodium bicarbonate in high-intensity and prolonged duration exercises, with the potential to induce muscle acidosis, is beneficial [21].

In a study by Cameron *et al.* [23], supplementation of 0.3 g/kg of body weight 65 minutes before exercise attenuated the drop in blood pH compared to the placebo group during high-intensity exercise in well-trained rugby players.

It also demonstrated improvement in the performance of athletes in athletics, in the 400 and 800 m events, and swimming, in the 100 and 200 m events [22,25], which have similar characteristics to the sprints performed in the finals of race events.

As for body composition, it can be observed that both groups showed changes in body composition between pre and post-supplementation moments, with no differences between them. It is believed that the changes are due to the training routine since the caloric intake was maintained in both moments of the study. Although the assessment of changes in body composition was not an objective of the present study, a possible weight reduction in only one of the groups could impact the performance of athletes in running [26].

Regarding side effects, some disorders in the gastrointestinal system have been reported in the literature when doses starting from 0.4 g/kg of body weight are used [9]. Although doses lower than those described were used, 50% of the runners had mild side effects when consuming the maximum dose suggested in the present study (0.3 g/kg body weight). However, as such effects appeared about two hours after the ingestion and the exhaustion test was completed before this period, there were no performance losses.

Conclusion

The study showed that sodium bicarbonate supplementation promoted performance improvement and urinary anion gap alteration in runners submitted to the exhaustion test.

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Potential conflict of interest
No conflict of interest has been reported.

Authors' contribution
Research conception and design: Menezes RO, Mendes RR; **Data acquisition:** Menezes RO, Santana IE; **Data analysis and interpretation:** Menezes RO, Gomes HH, Mendes RR; **Statistical analysis:** Gomes JH; **Obtaining financing:** Menezes RO, Mendes RR; **Manuscript writing: Menezes RO, Silva RJ, Mendes RR; Critical review of the manuscript for important intellectual content:** Mendes RR.

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