

Review

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Effect of sodium bicarbonate supplementation on two different performance indicators in sports: a systematic review with meta-analysis

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[Purpose] Sodium bicarbonate shows ergogenic potential in physical exercise and sports activities, although there is no strong evidence which performance markers show the greatest benefit from this supplement. This study evaluated the effects of sodium bicarbonate supplementation on time trial performance and time to exhaustion in athletes and sports practitioners.

[Methods] A systematic review was conducted using three databases, including 17 clinical trials. Among these clinical trials, 11 were considered eligible for the meta-analysis according to the criteria for the assessment of methodological quality using the PEDro Scale. Time to exhaustion was assessed in six studies, while time trial performance was evaluated in five studies.

[Results] A significant beneficial effect of supplementation on time to exhaustion was found in a random effects model (1.48; 95% confidence interval [CI], 0.49 to 2.48). There was no significant effect of supplementation on time trial performance in a fixed effects model (slope = -0.75; 95% CI, -2.04 to 0.55) relative to a placebo group.

[Conclusion] Sodium bicarbonate has the potential to improve sports performance in general, especially in terms of time to exhaustion.

[Key words] sodium bicarbonate, performance, supplementation, endurance

INTRODUCTION

The use of nutritional supplements as ergogenic resources has been shown to be efficient, as it delays the emergence of fatigue and increases the contractility of the skeletal muscle, improving the ability to perform physical activities and consequently improving sports performance^{1,2}. Fatigue is defined as any reduction in the ability to produce strength or power in a muscle or a group of muscles induced by exercise³. Although its precise etiology remains controversial, the accumulation of H⁺ and concomitant reduction in sarcoplasmic pH are considered to be the main causes of fatigue caused by training^{4,5}.

Taking into consideration the buffering capacity for the removal of H⁺ ions and the delay in the inhibition of glycolytic enzymes (especially phosphofructokinase), the use of nutritional supplements is a relevant approach to improving performance^{1,6}. According to the *American College of Sports Medicine*, many substances are potentially effective in improving buffering capacity, including sodium bicarbonate (NaHCO₃)⁷. Consequently, it is believed that supplementation with alkalizing agents before exercise can reduce the metabolic acidosis that occurs during heavy exercise, increasing the buffering capacity, and delaying the start of acidosis and fatigue^{4,8}.

McNaughton et al.⁹ showed that NaHCO₃ supplementation is efficient in athletes who practice a variety of exercises, such as supramaximal exercise and intermittent high-intensity activity. Previously published studies have demonstrated an improvement in acute muscle resistance in strength training¹⁰, delayed ventilatory threshold at Crossfit¹¹, improvement in lactate buffering in cyclists¹², greater glycolytic contribution in taekwondo³, and increased time to fatigue in long-distance road running¹³.

Although these studies have explored the effects of acute NaHCO₃ intake, according to various aspects of performance, there are still gaps in the literature regarding acute and/or chronic supplementation and its effects on time trial performance and time to exhaustion. Therefore, the objective of this systematic review and meta-analysis was to evaluate the

effects of sodium bicarbonate supplementation on time trial performance and time to exhaustion in athletes and sports practitioners.

METHODS

Experimental design

The study was a systematic review with meta-analysis performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines¹⁴.

Inclusion and exclusion criteria

Clinical trials that evaluated the effects of NaHCO₃ supplementation on sports performance, specifically in time trial performance and/or time to exhaustion, in athletes and sports practitioners who were healthy and had had NaHCO₃ supplementation before sports performance with a control group for comparison were included. Studies that used another supplement associated with NaHCO₃, did not have a defined intervention protocol, or observed secondary performance outcomes were excluded.

Data extraction

The PubMed, Scopus (Science Direct), and Virtual Health Library (VHB-BVS in Latin America) databases were searched for studies that had been published until 2020 in Portuguese, English, Spanish, or German. The latest included study was published on January 29, 2020.

Search strategy

The following search terms were used for the PubMed database using synonyms for sodium bicarbonate and performance found in the MeSH and Health Science Descriptors (Decs): (((((performance) OR athletic performance) OR sports performance) OR sports performances) OR athletic performances)) AND (((sodium bicarbonate) OR carbonic acid monosodium salt) OR sodium hydrogen carbonate) OR baking soda).

Quality assessment

The research was conducted by two independent researchers using the adopted search strategy and the databases mentioned above. Duplicate articles were removed, and filtering was performed according to eligibility criteria based initially on the study titles, followed by the abstracts and full text. The remaining studies were filed according to the PICO strategy, included in the systematic review, and filtered through the PEDro Scale¹⁵ for the identification of risk of bias and assessment of methodological quality. Those with ≥ 7 points on the PEDro scale were selected for inclusion in the meta-analysis. A third evaluator was included when there were divergent results.

Statistical analysis

The studies included in the meta-analysis were grouped according to the performance outcome subgroup. The standardized mean difference was used, according to Cohen's d,

for the analysis of results. Statistical heterogeneity was evaluated using Cochran's q test and tests of inconsistency for the analysis of symmetry and asymmetry in the funnel plot. In cases of high heterogeneity, defined as $I^2 \geq 50\%$, a random-effects model was used. For heterogeneity with values $< 50\%$, a fixed-effects model was used. The size of the individual-specific effect was calculated with a 95% confidence interval (CI). Analyses were performed using RevMan 5.3 from the Cochrane Collaboration, 2014.

Register

The International Prospective Register of Systematic Reviews (PROSPERO) is an international database of systematic reviews. Among the criteria for acceptance and registration, the systematic review must have a solely and exclusively health-related outcome. The present study does not meet the criteria for registration as it has a performance-related outcome.

RESULTS

Selection of studies

Figure 1 shows the flowchart of the search process and identification of studies to be included in the systematic review with meta-analysis. Initially, 172 articles were identified and 11 articles were included in the final analysis.

Characteristics of the studies

Table 1 shows the characteristics of the 17 clinical trials that were included in the systematic review, with a total of 393 participants aged 18 to 35 years. The studies were published until January 2020 and evaluated the effects of NaHCO₃ supplementation in diverse sports and varied evaluative and supplementary protocols.

Classification of risk of bias

Table 2 shows the clinical trials included in the systematic review and their respective PEDro Scale scores; Figure 2 shows the risk of bias assessed using the Cochrane Collaboration's tool, 2019/2020. To reduce the risk of bias, only studies with a score ≥ 7 for their methodological quality were included in the meta-analysis.

Results of individual studies according to the outcome

Time trial performance

Based on the heterogeneity among studies found in the analysis of the funnel chart and its respective symmetry (Figure 3), a fixed-effects model was adopted for the meta-analysis of the results. Five studies¹⁶⁻²⁰ with a total of 70 participants evaluated time trial performance following sodium bicarbonate or placebo supplementation. A non-significant favoritism bias was observed in the groups that used received placebo supplementation showed non-significantly better performance (slope = -0.75 ; 95% CI, -2.04 to 0.55 ; Figure 4).

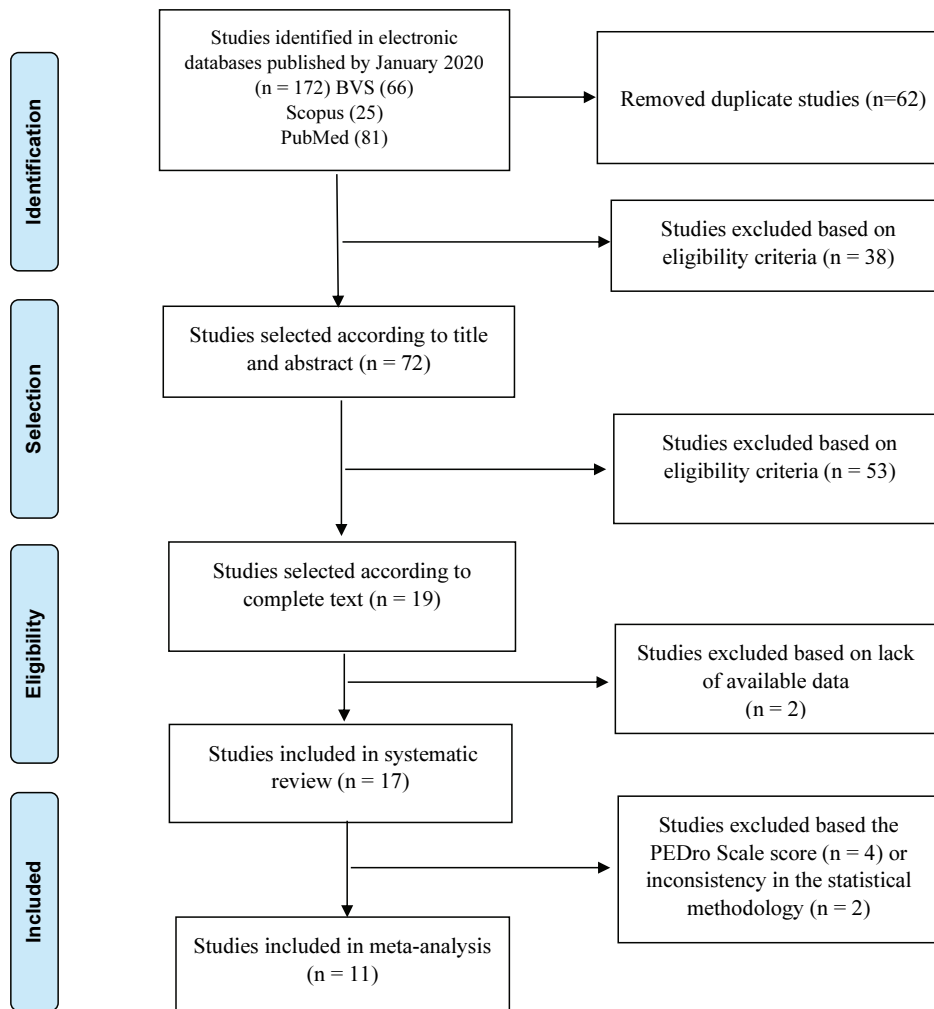


Figure 1. Flow diagram of the literature search and selection process - PRISMA.

Table 1. Characteristics of the 17 clinical trials included in the systematic review

Author	Number at GC (n _C); Number at GE (n _E); Mean age and SD (I)	Sport modality (Sport); Evaluation protocol (Protocol)	Placebo substance of control group (Sup _C); Supplementation of the experimental group (Sup _E)	Time trial in seconds (TT); Time to exhaustion in seconds (TE)	Model of Clinical Trial
Price et al. ³⁰	n _C : 8 n _E : 8 I: 20.3±1	Sport: Running Protocol: 20×24 s at 100% vVO ₂ , followed by 1× up to exhaustion at 120% vVO ₂	Sup _C : 45 mg/kg/pc of sodium chloride (NaCl) Sup _E : 0.3 g/kg/pc of BS, 60 minutes before the protocol	TE C: 75±22 TE E: 78±22	Randomized
Siegler et al. ³¹	n _C : 6 n _E : 6 I: Non-specified	Sport: Swimming Protocol: 8×25 m at 100% with 5-s intervals	Sup _C : 45 mg/kg/pc of sodium chloride (NaCl) Sup _E : 0.3 g/kg/pc of BS, 150 minutes before the protocol	TT C: 163.2±25.6 TT E: 159.4±25.4	Randomized, single-blind
Joyce et al. ¹⁹	n _C : 8 n _E : 8 I: 19±3	Sport: Swimming Protocol: 1×200 m at 100%	Sup _C : Methylcellulose capsules Sup _E : 0.1 g/kg/pc of BS, 3×/day for 3 days before the protocol	TT C: 119.02±5.82 TT E: 118.53±5.64	Randomized, double-blind
Danaher et al. ⁸	n _C : 8 n _E : 8 I: 26.2±1,9	Sport: Cycling Protocol: 1×110% Wmax till exhaustion at 80–100 rpm	Sup _C : 0.3 g/kg/pc of calcium carbonate (CaCO ₃) Sup _E : 0.3 g/kg/pc of BS, 90 minutes before the protocol	TE C: 129±10.94 TE E: 132±13.48	Randomized, crossover, double-blind.

Author	Number at GC (nC); Number at GE (nE); Mean age and SD (I)	Sport modality (Sport); Evaluation protocol (Protocol)	Placebo substance of control group (SupC); Supplementation of the experimental group (SupE)	Time trial in seconds (TT); Time to exhaustion in seconds (TE)	Model of Clinical Trial
Egger et al. ²³	nC: 21 nE: 21 I: 24±8	Sport: Cycling Protocol: 1×30min at 95% IAT, followed by 1× until exhaustion at 110% IAT	SupC: 4 g of sodium chloride (NaCl) SupE: 0.3 g/kg/pc of BS, 60 minutes before the protocol	TE C: 2700±570 TE E: 2970±690	Randomized, crossover; double-blind
Hobson et al. ¹⁸	nC: 20 nE: 20 I: 23±4	Sport: Rowing Protocol: 2×2 km at 100%, with an interval of 48 h between assessments.	SupC: 0.3 g/kg/pc of maltodextrin SupE: 0.2 g/kg/pc of BS, 240 minutes before the protocol and 0.1 g/kg/pc of BS 60 minutes before the protocol	TT C: 412±15.1 TT E: 410.7±14.9	Randomized, crossover, double-blind
Callahan et al. ³²	nC: 8 nE: 8 I: 34.7±7	Sport: Cycling Protocol: 1×4 km at 100%	SupC: 0.3 g/kg/pc of maltodextrin SupE: 0.3 g/kg/pc of BS, 150 minutes before the protocol	TT C: 338.1±18.04 TT E: 335.78±16.94	Double-blind
Freis et al. ¹³	nC: 18 nE: 18 I: 27.9±9.1	Sport: Race Protocol: 1×30 min at 95% IAT, followed by 1× until exhaustion 110% IAT	SupC: 4g of sodium chloride (NaCl) SupE: 0.3 g/kg/pc of BS, 90 minutes before the protocol	TE C: 2358±336 TE E: 2376±336	Randomized, crossover, double-blind
Gough et al. ¹⁶	nC: 11 nE: 11 I: 32±9	Sport: Cycling Protocol: 1×4 km at 100%	SupC: Water and gooseberry SupE: 0.3 g/kg/pc of BS, evaluating the levels of blood BS up to the peak	TT C: 381.7±13.1 TT E: 373.5±13.1	Randomized, double-blind
Gough et al. ²¹	nC: 9 nE: 9 I: 23±2	Sport: Cycling Protocol: 2×100% until exhaustion with 90-min interval	SupC: 0.1 g/kg/pc of sodium chloride (NaCl) SupE: 0.3 g/kg/pc of BS, 90 minutes before the protocol	TE C: 211±65 TE E: 246±70	Crossover, double-blind.
Delextrat et al. ¹⁷	nC: 15 nE: 15 I: 23.3±3.4	Sport: Basketball Protocol: 17× <i>BEST</i> protocol (Sprint, race, change direction and jumps)	SupC: Non-specified SupE: 0.4 g/kg/pc of BS, for 3 days before the protocol	TT C: 31.3±1.96 TT E: 30.58±2.03	Randomized, crossover, double-blind
Macut-kiewicz et al. ³³	nC: 8 nE: 8 I: 23±5	Sport: Field hockey Protocol: 6× <i>FHST</i> protocol (Dribbles, passes and kicks - from beacon)	SupC: 0.2 g/kg/pc of maltodextrin SupE: 0.3 g/kg/pc of BS, 90 minutes before the protocol	TT C: 87.9±6.9 TT E: 89±7.8	Randomized, crossover, single-blind
Ferreira et al. ¹²	nC: 21 nE: 21 I: 20±2	Sport: Cycling Protocol: 3× until exhaustion at 80 rpm and load of 5%, with 7-d interval	SupC: 0.3 g/kg/pc of calcium carbonate (CaCO ₃) SupE: 0.3 g/kg/pc of BS, 30 minutes before the protocol	TE C: 68.03±5.41 TE E: 76.42±4.41	Randomized, crossover, double-blind
Gough et al. ³⁴	nC: 7 nE: 7 I: 27.1±5.1	Sport: Boxing Protocol: 1×90% VO ₂ , with 3×3 min simulation of round and 1×90% VO ₂ , with 75-min interval between each assessment	SupC: 0.1 g/kg/pc of sodium chloride (NaCl) SupE: 0.3 g/kg/pc of BS, 60 minutes before the protocol	TE C: 73±78 TE E: 164±90	Double-blind
Peinado et al. ³⁵	nC: 12 nE: 12 I: 19.2±3.4	Sport: BMX cycling Protocol: 3×400 m at 100%, on an official course with a 15-min interval between each assessment	SupC: 45 mg/kg/pc of sodium chloride (NaCl) SupE: 0.3 g/kg/pc of BS, 90 minutes before the protocol	TT C: 31.32 (30.60–32.05) TT E: 31.37 (30.65–32.10)	Randomized, crossover, double-blind
Rezaei et al. ²²	nC: 8 nE: 8 I: 20.5±2.4	Sport: Karate Protocol: 2× sequences of blows at 100%, until exhaustion with progressive reduction of interval.	SupC: Cellulose capsules SupE: 0.1 g/kg/pc of BS at 120, 90, and 60 min before the protocol	TE C: 636±39 TE E: 693±28	Randomized, crossover, double-blind
Voskamp et al. ²⁰	nC: 16 nE: 16 I: 27.6±6.9	Sport: Cycling Protocol: 1×2 km at 100%	SupC: Sunflower oil and magnesium capsules SupE: 0.3 g/kg/pc of BS, 150 minutes before the protocol	TT C: 164.2±5 TT E: 164.3±5	Randomized, crossover, double-blind

VO₂: volume of oxygen that is captured and distributed in the body; vVO₂, velocity of VO₂; Wmax, maximum power in watts; IAT, individual anaerobic threshold; *BEST*, basketball exercise stimulation test; *FHST*, field hockey skill test; rpm, rotations per minute; BW, body weight; g/kg/pc, grams per kilogram of body weight; mg/kg/pc, milligrams per kilogram of body weight; C: control group; E: experimental group.

Table 2. Methodological qualification of the studies based on PEDro Scale for inclusion in the meta-analysis (2020)

Author	Score (0-11)	Items from the PEDro Scale										
		1	2	3	4	5	6	7	8	9	10	11
Price et al.	5	N	Y	N	Y	N	N	N	N	Y	Y	Y
Siegler et al.	6	N	Y	N	N	Y	N	N	Y	Y	Y	Y
Joyce et al.	10	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Danaher et al.	9	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Egger et al.	8	N	Y	N	Y	Y	Y	N	Y	Y	Y	Y
Hobson et al.	8	N	Y	N	Y	Y	Y	N	Y	Y	Y	Y
Callahan et al.	6	N	N	N	Y	Y	Y	N	N	Y	Y	Y
Freis et al.	8	N	Y	Y	Y	Y	Y	N	N	Y	Y	Y
Gough et al.	8	Y	Y	N	Y	Y	Y	N	N	Y	Y	Y
Gough et al.	7	Y	N	N	Y	Y	Y	N	N	Y	Y	Y
Delextrat et al.	7	N	N	Y	Y	Y	Y	N	N	Y	Y	Y
Macutkiewicz et al.	6	N	Y	N	Y	Y	N	N	N	Y	Y	Y
Ferreira et al.	9	Y	Y	N	Y	Y	Y	N	Y	Y	Y	Y
Gough et al.	8	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y
Peinado et al.	7	N	Y	N	Y	Y	Y	N	N	Y	Y	Y
Rezaei et al.	10	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Y: Yes (meet the criterion); N: No (does not meet the criterion)

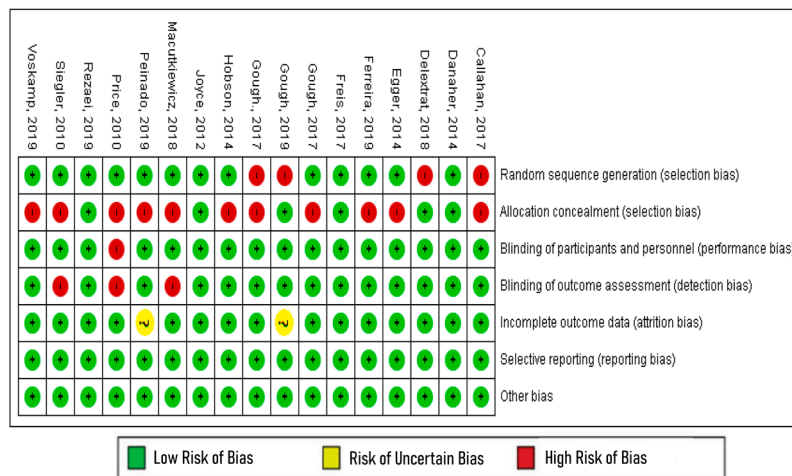


Figure 2. Evaluation of the risk of bias of the eight studies included in the review based on the Cochrane Collaboration’s tool, 2019/2020.

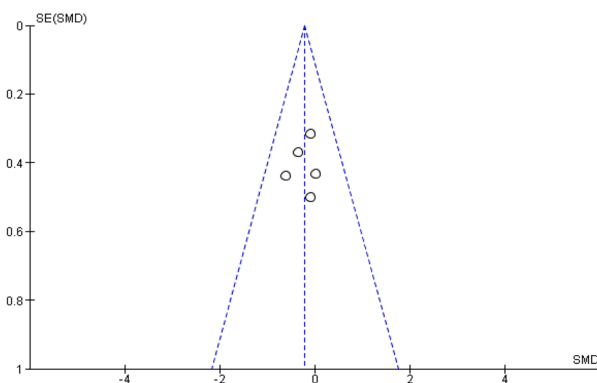


Figure 3. Funnel plot of the five studies that analyzed time trial performance.

Sodium bicarbonate supplementation and sports performance

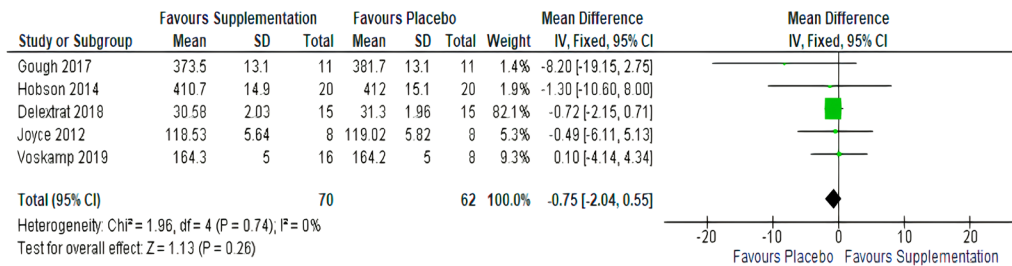


Figure 4. Forest plot of the relationship between placebo or sodium bicarbonate supplementation and time trial performance as a performance marker.

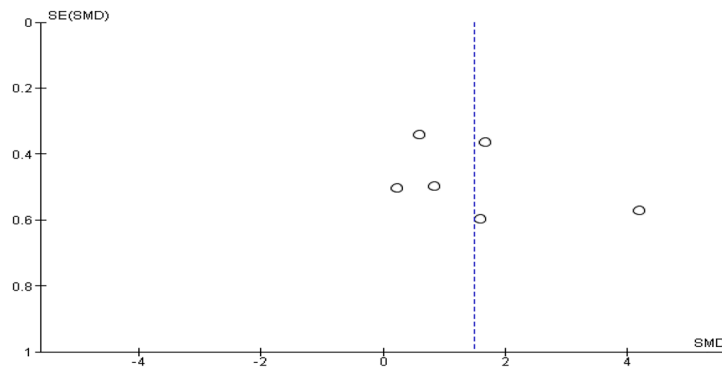


Figure 5. Funnel chart of the six studies that analyzed time to exhaustion as an outcome.

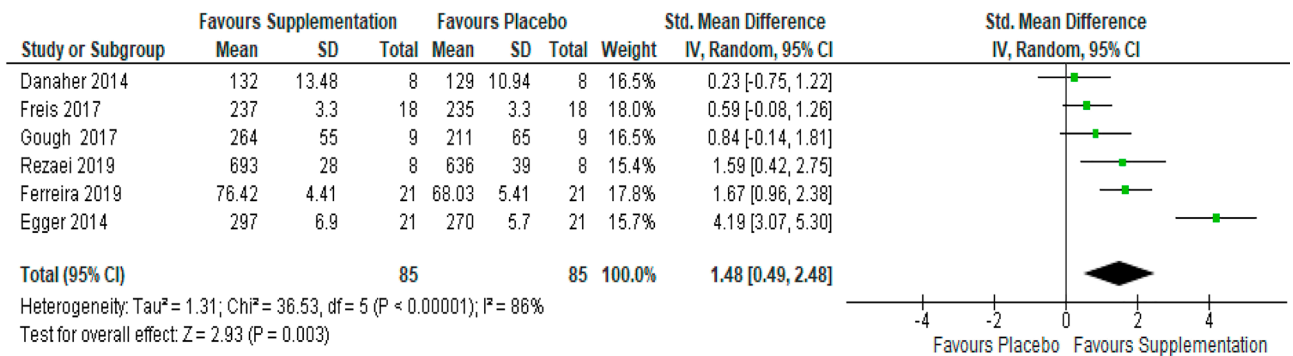


Figure 6. Forest plot of the relationship between placebo or sodium bicarbonate supplementation and time to exhaustion as a performance marker.

Time to exhaustion

Based on the heterogeneity among studies found in the analysis of the funnel chart and its respective asymmetry (Figure 5), a random-effects model was adopted for the meta-analysis of the results. Six studies^{8,12,13,21-23} with a total of 85 participants evaluated the total time to exhaustion in the performed interventions following NaHCO₃ or placebo supplementation. Groups that used NaHCO₃ supplementation showed significantly better performance (SMD 1.48; 95% CI, 0.49 to 2.48; Figure 6).

DISCUSSION

The present systematic review and meta-analysis evaluated randomized clinical trials of NaHCO₃ supplementation and its effects on sports performance in athletes and sportspeople. Our findings show that NaHCO₃ has an ergogenic effect on time to exhaustion during exercise, but not on time trial performance. In practice, supplementation can increase the number of repetitions with a certain load or over a certain time to maintain power training at a higher intensity. These findings are based on studies that made use of a dosage of 0.3 g/kg 3 days, 240, 150, and 90 minutes before exercise^{8,12,13,21-23}.

Previous studies corroborate the results of our meta-analysis when demonstrating the ergogenic effect of supplementation on time to exhaustion as a measure of performance^{12,22,23}. On the other hand, some studies^{8,13,21} did not find a beneficial effect in time to exhaustion but found beneficial effects on metabolic markers, such as increased blood lactate concentration and glycolysis capacity during exercise. Danaheer et al.⁸ used a protocol that consisted of initial supramaximal efforts, which may have contributed to the low beneficial effect of NaHCO₃ in the maintenance of participants' physical effort.

Interestingly, Hadzic et al.²⁴ in their systematic review of randomized and controlled studies, analyzed the effects of NaHCO₃ supplementation on performance during <4 mins and >4 mins exercise, so that they could contemplate diverse exercise and modalities, including cycling, swimming, running, boxing, tennis, and taekwondo, and their metabolic specificities. According to the authors, the duration of exercise is the main factor explaining the possible beneficial effects of NaHCO₃. Our study showed that out of the six studies that demonstrated an ergogenic effect on time to exhaustion, four studies had >4 min exercise duration, with a maximum of 49.5 min²³. Thus, it seems that factors other than the duration of exercise are associated with the outcomes of NaHCO₃ supplementation.

These factors include training level (e.g., amateur, elite), and sex. Trained athletes have higher tamponade capacity and are, consequently, less responsive to supplementation²⁵. On the other hand, NaHCO₃ is efficient in athletes who are trained using diverse exercises, such as supramaximal exercises and intermittent high-intensity sports activities, based on their abilities⁹. The lack of consensus in the literature demonstrates that the relationship between conditioning level and responsiveness to NaHCO₃ remains inconclusive.

The reasons for the contrasting results between the studies are worth discussion, as the methodological limitations of the studies, make it possible to understand these discrepancies and highlight questions to be answered in further research. We observed that the studies had heterogeneous small sample sizes (the largest sample size in our review was 42 individuals), including individuals with varying levels of conditioning and sex, performing different exercise modalities. Regarding sex, it is important to highlight that the menstrual cycle can alter performance, and this is usually ignored. Furthermore, women showed more time to exhaustion in repetitive sprint exercises²⁶. Factors associated with oxidative and glycolytic capacity, as well as neural factors, seem to be involved. Another factor that is associated with misunderstandings in the literature is the presence of "responsive" and "non-responsive,"²⁷ so that mechanisms that explain these different phenomena are unknown.

However, in this context, most included studies were double-blinded crossover studies, which are the "gold standard." Nevertheless, none of these studies explained the efficacy of blindness by asking the participants to state which of the supplements was NaHCO₃ and which was placebo. Once NaHCO₃ is associated with side effects, such as gastrointestinal problems, it is possible that some participants

may have identified the experimental treatment and thus influenced the results.

The dosages used and NaHCO₃ preparation varied significantly. Most studies used 0.3 g of NaHCO₃ per kg of body weight acutely (up to 240 minutes before the exercise). In addition, the pharmaceutical type used varied, including jelly capsules, tablets, and fluid solutions^{8,12,13,16,20,21,23}. On the other hand, the effects of type (fluid solution or capsule) and time of consumption are also not clear, because the results of acute (0.5–4 h before exercise) or chronic intake of NaHCO₃ (three days before exercise) led to similar results^{17,19}. This usual dosage is associated with gastrointestinal disorders, which may reduce athletes' acceptance of the use of NaHCO₃^{6,7}. A method of avoiding this discomfort referred to as "loading," has been discussed in the literature²⁸. The accumulation of CO₂ in the intestine, due to supplementation, may cause abdominal distension and pain, nausea, and vomiting, which are serious and diverse types of side effects⁹.

Only two studies performed loading^{17,19}. Loading is the intake of small dosages of bicarbonate throughout the day, usually around three times (together with main meals). Theoretically, this protocol can be used in preparation for many events on successive days or to avoid periods of a high risk of intestinal disorders (close to physical exercise). Freis et al. noted that chronic intake of NaHCO₃ can increase the risk of cardiac dysrhythmia due to alterations in the concentration of potassium in the blood and urolithiasis due to the alkalization of the urine and sodium content¹³. Some authors, however, suggest that chronic use may be better than acute use^{9,29}. After loading, plasma concentrations of bicarbonate are maintained even after the interruption of supplementation, so that blood can store extra NaHCO₃ and use it.

The works that had been included in the present systematic review are, in general, of good quality. An inherent but inevitable problem in studies of supplementation is the high risk of bias, as multiple factors can influence the outcomes. As previously mentioned, sample blinding has not been fully explained in detail. In addition, food intake during the experimental protocols has not been reported.

The results presented in this review confirm the potential of NaHCO₃ to increase time to exhaustion. Future studies with long-term supplementation are needed to determine whether chronic supplementation improves adaptation to physical training. Moreover, it is suggested that studies that consider the guarantee the efficacy of the blinding for the placebo and NaHCO₃ conditions and compare the results between individuals that can identify NaHCO₃ from those who cannot. Another point that needs attention is the shortage of studies that investigated supplementation in women and older people, so future studies should address this gap in the current literature.

The limitations of our study were the methodological classification of articles after filtering based on eligibility criteria. The classification of risk of bias was a determinant for the inclusion of studies in the meta-analysis¹⁵; therefore, some studies with relevant results may have been excluded

due to lack of data or their partial provision. It is important to note that the variables associated with performance and fatigue are multifactorial, such as the time of intake of the supplement and the level of training of sports activity practitioners. However, specifically investigated the use of NaHCO_3 supplementation on the time trial performance and resistance to fatigue in general. Thus, future investigations should consider the influence of different intervening factors on performance indicators to better understand this phenomenon.

In conclusion, supplementation with NaHCO_3 has been used by coaches, physical trainers, and nutritionists in sports. The findings of this investigation indicate that supplementation with NaHCO_3 may improve the sports performance of athletes and practitioners of sports, so that time to exhaustion may be the most beneficial performance marker of this supplement, while time trial performance seems not to be influenced by NaHCO_3 supplementation. The findings of this review provide relevant information for sports professionals to make strategic decisions aimed at increasing their performance of athletes and sports practitioners in a specific way.

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