Effects of Sodium Bicarbonate Ingestion on Measures of Wingate Test Performance: A Meta-Analysis

Effects of sodium bicarbonate ingestion on measures of Wingate test performance: a meta-analysis

Jozo Grgic,[1]

[1]Institute for Health and Sport (IHES), Victoria University, Melbourne, Australia

Short title: Sodium bicarbonate and Wingate

Number of tables: 2

Number of figures: 3

Abstract word count: 248

Manuscript word count: 3305

Corresponding author

Jozo Grgic

jozo.grgic@live.vu.edu.au

Institute for Health and Sport (IHES), Victoria University, Melbourne, Australia

Grgic, J. (2020). Effects of sodium bicarbonate ingestion on measures of Wingate test performance: a meta-analysis. *Journal of the American College of Nutrition.* Published ahead of print.

Effects of sodium bicarbonate ingestion on measures of Wingate test performance: a meta-analysis

Abstract

The review aimed to perform a meta-analysis of studies examining the acute effects of sodium bicarbonate on Wingate test performance. Ten databases were searched to find studies that examined the effects of sodium bicarbonate on single and repeated Wingate tests. Meta-analyses were performed using the random-effects model. Ten studies were included in the review. There was no significant difference between the sodium bicarbonate and placebo trials for mean power in Wingate test 1 (standardized mean difference [SMD] = 0.02; 95% confidence interval [CI]: –0.07, 0.11) and test 3 (SMD = 0.21; 95% CI: –0.16, 0.58). There was a significant effect of sodium bicarbonate on mean power in Wingate test 2 (SMD = 0.09; 95% CI: 0.03, 0.16), and test 4 (SMD = 0.62; 95% CI: 0.15, 1.08). When considering studies that used shorter rest intervals between repeated Wingate tests, a significant effect of sodium bicarbonate was found on mean power in Wingate test 3 (SMD = 0.40; 95% CI: 0.01, 0.80). There was no significant difference between the sodium bicarbonate and placebo trials for peak power in Wingate test 1 (SMD = –0.01; 95% CI: –0.06, 0.04), test 2 (SMD = 0.02; 95% CI: –0.10, 0.13), or test 4 (SMD = 0.29; 95% CI: –0.13, 0.71). There was a significant effect of sodium bicarbonate on peak power in test 3 (SMD = 0.09; 95% CI: 0.00, 0.17). The results of this review suggest that sodium bicarbonate may provide an ergogenic effect on measures of repeated Wingate test performance.

Keywords: supplements; ergogenic aid; sprints; NaHCO3

Introduction

The ergogenic effects of sodium bicarbonate on exercise performance have been explored since the 1930s (1). Current findings indicate that sodium bicarbonate may be acutely ergogenic for performance in different exercise activities, such as swimming, boxing, rowing, and resistance exercise (2-7). Sodium bicarbonate is most commonly provided in the dose of 0.3 g per kg of body mass, 60 to 120 minutes before exercise (8, 9). The central mechanism by which sodium bicarbonate increases exercise performance is associated with its effects on dynamic buffering capacity (8, 9). During high-intensity exercise, there is an increased accumulation of hydrogen ions (H^+). Increased H^+ accumulation may lead to intramuscular acidosis (i.e., a decrease in pH), and acidosis has been identified as a factor that contributes to fatigue and a decline in exercise performance (8, 9). The main goal of supplementing with sodium bicarbonate is to increase blood bicarbonate levels. In resting conditions, the circulating concentrations of bicarbonate commonly range from 23 and 27 $mmol \cdot L^{-1}$ (8, 9). Studies that provide sodium bicarbonate in doses of 0.2 to 0.3 $g \cdot kg^{-1}$ report increases in blood bicarbonate from baseline levels by 5 to 6 $mmol \cdot L^{-1}$ (8, 9). This increase in blood bicarbonate is coupled with an increase in extracellular buffering, leading to a greater efflux of H^+ out of the muscles active during exercise into the circulation (8, 9). An increase in the rate at which accumulating H^+ is removed from muscles active during exercise may contribute to intramuscular pH maintenance, which may ultimately enhance performance (8, 9).

The Wingate test is commonly used to evaluate high-intensity exercise performance (10). In general, the Wingate test includes “all-out” cycling for 30 seconds on a cycling ergometer (10). The primary outcomes of this test are peak and mean power. Peak power is the maximal power achieved during any given five seconds of the test (usually in the first five seconds) (10). Mean power is the average power recorded during the whole duration of the test. Several studies explored the effects of sodium bicarbonate ingestion on Wingate test performance (2, 11, 12). However, the findings are equivocal as some studies reported an ergogenic effect of acute sodium bicarbonate ingestion on Wingate performance measures, while others did not find significant differences between the sodium bicarbonate and placebo conditions (2, 11, 12).

One limitation of the studies conducted on this topic is that they tend to involve small sample sizes and may be statistically underpowered. For example, one of the early studies included only six participants (13). One way to overcome the possible low statistical power of individual studies is to perform a meta-analysis. Meta-analysis is a statistical method that allows the combining of data from different cohorts to obtain a pooled effect size. Such an analysis may help elucidate the inconsistent evidence of sodium bicarbonate effects on Wingate performance. Accordingly, this paper aimed to conduct a systematic review of studies examining the effects of sodium bicarbonate on Wingate performance and analyze their results using a meta-analysis.

Materials and methods

Search strategy

Searches for studies were conducted through ten databases, including: Academic Search Elite, CINAHL, ERIC, Networked Digital Library of Theses and Dissertations, Open Dissertations, Open Access Theses and Dissertations, PubMed/MEDLINE, SPORTDiscus, Scopus, and Web of Science. In all databases, the following search syntax was used: ("sodium bicarbonate" OR NaHCO3 OR alkalosis) AND (Wingate OR "mean power" OR "peak power"). Secondary searches were performed by: (a) examining the reference lists of previous related reviews (14-17) and all included studies; and, (b) conducting forward citation tracking through Google Scholar and Scopus.

Inclusion criteria

Studies that satisfied the following criteria were included:

1. Explored the effects of isolated sodium bicarbonate ingestion on performance in the 30-second cycling Wingate test
2. Utilized a crossover, placebo-controlled study design
3. Included humans as study participants

Studies were excluded from consideration if these criteria were not satisfied. The most common reason for exclusion is that the study did not use a Wingate test protocol.

Data extraction

From all included studies, the following data were extracted:

1. Study authors and year of publication
2. Sample characteristics
3. Sodium bicarbonate supplementation protocol
4. Side-effects associated with sodium bicarbonate ingestion
5. pH and blood bicarbonate values (if measured)
6. Wingate test protocol
7. Main study findings

For one study (2) that presented data in a figure, the data were extracted using the Web Plot Digitizer software (https://apps.automeris.io/wpd/). For one study (11) that presented standard errors (SEs), the data were converted to standard deviation (SD).

Methodological quality

Study quality was assessed using the PEDro checklist (18). This checklist has 11 items that refer to eligibility criteria, randomization, allocation concealment, blinding of participants, therapists, and assessors, attrition, and data reporting. Each item is scored with a “1” if the criterion is satisfied or with a “0” if the criterion is not satisfied. Even though this checklist has 11 items, the first item is not included in the summary score. Therefore, the maximum possible score on the checklist was 10 points. Based on the summary scores, studies were classified as “excellent methodological quality” (9–10 points), “good methodological quality” (6–8 points), “fair methodological quality” (4–5 points), and “poor methodological quality” (≤3 points) (19, 20).

Statistical analysis

Meta-analyses were performed using standardized mean differences (SMD). The performance mean ± SD data recorded in the sodium bicarbonate and placebo trials were converted to SMDs and 95% confidence intervals (CIs). SMDs were calculated based on the performance mean ± SD data, total sample size, and inter-trial correlation. Given that studies did not present inter-trial correlation, correlation was estimated using the formula provided in the

Cochrane Handbook (21). Meta-analyses were performed for mean and peak power. For both outcomes, analyses were performed for single Wingate sprint (i.e., test 1), and for repeated Wingate tests (i.e., tests 2, 3, and 4). In the analyses for mean and peak power in tests 2 and 3, a sensitivity analysis was performed by excluding two studies by Zabala et al. (22, 23) as these studies used very long rest intervals (15 and 30 minutes, respectively) between the repeated Wingate tests. All analyses were performed using the random-effects model. SMD values were interpreted as trivial (<0.20), small (0.20–0.39), medium (0.40–0.59), large (0.60–0.80), and very large (>0.80). Heterogeneity was explored using the I^2 statistic. I^2 values of <50%, 50–75%, and >75% were considered as low levels, moderate levels, and high levels of heterogeneity. The statistical significance threshold was set at $p < 0.05$. All analyses were performed using the Comprehensive Meta-analysis software, version 2 (Biostat Inc., Englewood, NJ, USA).

Results

Search results

In the primary and secondary search, there was a total of 1981 potentially relevant references. After excluding the documents based on title, abstract, or full-text, ten studies were included in the review and meta-analysis (2, 11-13, 22-27).

Study details

The pooled number of participants in the 10 included studies was 108 (median per study: 10 participants; range: 6 to 15 participants). Nine studies provided sodium bicarbonate dose relative to individual participant's body mass, while one used an absolute dose of 10 grams (Table 1). In the studies that used relative doses, the doses ranged from 0.2 to 0.5 $g \cdot kg^{-1}$. The timing of ingestion was from 60 to 180 minutes before exercise. Seven studies used repeated Wingate protocols that included two to four Wingate tests. Rest intervals between tests ranged from 1 to 30 minutes.

Methodological quality

Seven and three studies were categorized as being of excellent methodological quality and moderate methodological quality, respectively (Table 2). None of the studies included in this review were categorized as being of poor quality.

Meta-analysis results – mean power

There was no significant difference between the sodium bicarbonate and placebo trials for mean power in Wingate test 1 (SMD = 0.02; 95% CI: –0.07, 0.11; $p = 0.688$; $I^2 = 0\%$; Figure 2) and in Wingate test 3 (SMD = 0.21; 95% CI: –0.16, 0.58; $p = 0.268$; $I^2 = 0\%$). Compared to placebo, there was a significant effect of sodium bicarbonate on mean power in Wingate test 2 (SMD = 0.09; 95% CI: 0.03, 0.16; $p = 0.005$; $I^2 = 0\%$), and in Wingate test 4 (SMD = 0.62; 95% CI: 0.15, 1.08; $p = 0.009$; $I^2 = 0\%$). In the sensitivity analysis, there was no significant difference between the sodium bicarbonate and placebo trials for mean power in Wingate test 2 (SMD = 0.11; 95% CI: 0.00, 0.23; $p = 0.059$; $I^2 = 7\%$), even though a significant effect of sodium bicarbonate was found on mean power in Wingate test 3 (SMD = 0.40; 95% CI: 0.01, 0.80; $p = 0.046$; $I^2 = 0\%$).

Meta-analysis results – peak power

There was no significant difference between the sodium bicarbonate and placebo trials for peak power in Wingate test 1 (SMD = –0.01; 95% CI: –0.06, 0.04; $p = 0.730$; $I^2 = 0\%$; Figure 3), test 2 (SMD = 0.02; 95% CI: –0.10, 0.13; $p = 0.774$; $I^2 = 7\%$), or test 4 (SMD = 0.29; 95% CI: –0.13, 0.71; $p = 0.180$; $I^2 = 0\%$). Compared to placebo, there was a significant effect of sodium bicarbonate on peak power in test 3 (SMD = 0.09; 95% CI: 0.00, 0.17; $p = 0.048$; $I^2 = 0\%$). In the sensitivity analysis, there was no significant difference between the sodium bicarbonate and placebo trials in peak power in Wingate test 2 (SMD = 0.05; 95% CI: –0.11, 0.22; $p = 0.516$; $I^2 = 15\%$), even though a significant effect of sodium bicarbonate was found on peak power in Wingate test 3 (SMD = 0.13; 95% CI: 0.06, 0.19; $p < 0.001$; $I^2 = 0\%$).

Discussion

In this meta-analysis, there was no significant difference between sodium bicarbonate and placebo for single Wingate test mean and peak power. However, sodium bicarbonate was ergogenic for repeated Wingate performance, as evidenced by increases in mean power in Wingate tests 2 and 4, and the increases in peak power in test 3. Additionally, when considering only studies that used shorter duration rest intervals between Wingate tests, a significant effect was found on mean power in Wingate test 3. Overall, these results suggest that sodium bicarbonate may provide an ergogenic effect on measures of repeated Wingate test performance.

The physiological mechanisms of sodium bicarbonate may explain the finding that sodium bicarbonate may enhance repeated, but not single Wingate test performance. As mentioned previously, sodium bicarbonate enhances performance by increasing H^+ buffering during high-intensity exercise and subsequent intramuscular pH maintenance (8, 9). During rest, muscle pH levels are ~7.1 (9). However, after a single Wingate test, one study reported that pH is reduced to 6.7, and a reduction in pH levels is associated with muscle fatigue (28). Without sodium bicarbonate ingestion, the reduced pH after a single Wingate test would contribute to performance loss in repeated Wingate tests. However, sodium bicarbonate ingestion would allow for higher pH levels in subsequent Wingate test, thereby improving exercise performance. Additionally, it seems that the effects of sodium bicarbonate on Wingate performance increase with each subsequent test, as the SMDs for mean power amounted to 0.02, 0.09, 0.21, and 0.62 for tests 1, 2, 3, and 4, respectively. However, we should consider that the 95% CIs in some of these analyses overlapped, which is a limitation in making such conclusions.

Although a significant ergogenic effect of sodium bicarbonate was found on mean power in tests 2 and 4 (and in test 3 in the sensitivity analysis), improvements in peak power were observed only in test 3, but the effect was very small (SMD = 0.09). This is likely because peak power is thought to represent the ability of limbs to produce mechanical power in a short time, and peak power is commonly recorded within the first five seconds of the sprint (10). Mean power is more reflective of the endurance of the activated muscles, as this outcome represents the average power recorded during the 30-second sprint. In this context and given the mechanisms of sodium bicarbonate, it may be expected that this supplement would have more pronounced ergogenic effects on muscle endurance properties than on maximum power production (8, 9). Additionally, it might be that sodium bicarbonate is ergogenic on peak power only when a considerable amount of fatigue is induced, which might explain why a significant effect was found only in test 3.

One important consideration regarding the ergogenic effects of sodium bicarbonate on repeated Wingate test performance is the rest interval duration. One study measured pH levels after a Wingate test that included either 90 seconds, 3 minutes, or 6 minutes of recovery (28). Out of these three conditions, pH was the lowest after 90 seconds of rest and highest when a 6-minute rest interval was provided. Given the importance of rest for the time course of pH changes after a Wingate test, it can be hypothesized that sodium bicarbonate would provide greater ergogenic effects when using a protocol with a shorter rest interval. Indeed, two (22, 23) studies used 15 and 30 minutes of rest between Wingate tests and did not find an ergogenic effect of sodium bicarbonate ingestion. In contrast, Artioli et al. (2) used 3 minutes of rest and found ergogenic effects of sodium bicarbonate. When the two studies that used longer duration rest intervals were excluded in a sensitivity analysis, the pooled SMD for mean power in Wingate tests 3 increased from 0.21 (95% CI: –0.16, 0.58) to 0.40 (95% CI: 0.01, 0.80). Nevertheless, future studies may consider exploring the effects of sodium bicarbonate on repeated Wingate performance measures while using different rest intervals in the same group of participants.

The findings presented herein might be of relevance to different sports. For example, mean and peak power values in the Wingate test are associated with performance in bicycle motocross races (29). Wingate test results are also considered a strong predictor of 1500-m performance in elite speed skaters (30). Additionally, Wingate test performance is significantly correlated with performance in ice hockey-specific tests (31). Performance in the Wingate test may also be relevant to cyclists, as they commonly finish the race with an “all-out” sprint (32). Given that this review found that sodium bicarbonate ingestion may enhance Wingate test performance, it seems that this supplement may also positively impact sport-specific outcomes. Still, future work is needed to explore the effects of sodium bicarbonate ingestion directly in sport-specific situations.

Thus far, only one meta-analysis explored the effects of sodium bicarbonate on Wingate performance. Lopes-Silva et al. (14) included six studies and reported no significant difference between placebo and sodium bicarbonate for mean and peak power in single or repeated Wingate tests. These results likely differ from those presented herein because Lopes-Silva et al. (14) included only published studies, and no "grey literature" searches were performed. This should be considered given that unpublished studies may offer high-quality evidence despite their publication status. Additionally, since the publication of the review by Lopes-Silva et al. (14), there has been new research on the topic (26). The increase in the number of included studies in the present review resulted in narrower 95% CIs, giving the ability to detect small but potentially practically meaningful effects.

Although the included studies were classified as moderate or excellent methodological quality on the PEDro checklist, there are some specific limitations to research on sodium bicarbonate that need to be acknowledged. One study used a crossover design without any blinding (12). Even though this study reported similar SMDs as studies that incorporated blinding, this needs to be mentioned as the double-blind design is considered the "gold standard" in sports nutrition research. None of the studies that employed blinding of participants evaluated the effectiveness of this procedure by asking the participants to indicate which trial they perceived to be the sodium bicarbonate and which the placebo trial. Future studies should include this procedure because correct supplement identification may influence the outcome of a given test and be a source of bias (33). Although studies generally did not report any side-effects associated with sodium bicarbonate ingestion, it is unclear if there was an attempt to comprehensively record all possible side-effects. Side-effects associated with sodium bicarbonate can be quite severe (e.g., diarrhea, vomiting) (34, 35). Sodium bicarbonate ingestion may even be ergolytic for individuals that experience such side-effects (34, 35). Future studies should clearly specify all side-effects associated with sodium bicarbonate ingestion. Several included studies also did not measure blood bicarbonate levels after sodium bicarbonate ingestion, which is a limitation given that the increase in blood bicarbonate (from baseline to pre-exercise), is one of the key determinants of the ergogenic effects of this supplement (8, 9). Even though the goal of sodium bicarbonate is to increase blood bicarbonate levels, it should be taken into account that isolated ingestion of salt may also be ergogenic in some cases (36). However, only three included studies provided a placebo where the sodium content contained an equimolar amount of salt to the sodium bicarbonate dose.

Several studies specified that diet and fluid intake were standardized before the main trials (2, 26, 27). However, this information was not provided in all included studies (11, 12). Future research on this topic should endeavor to control diet and fluid intake as much as possible and to clearly report this information in their respective methods section. Future studies should address some of these limitations to improve the quality of research performed on this topic.

Future studies should also consider assessing other outcomes except mean and peak power. Specifically, studies should consider analyzing outcomes such as minimum power and power decrement to provide a more comprehensive depiction of sodium bicarbonate effects on Wingate test performance. Even though this review indicates that sodium bicarbonate may be ergogenic for Wingate test performance when looking at mean differences, the importance of individual responses has been recently acknowledged (37). While relevant, studies included in this review did not present individual participant data, which future studies should consider. Recommendations for researchers regarding the interpretation and reporting of personalized data is provided by Swinton et al. (37). Generally, it does not seem that training status impacted the responses to sodium bicarbonate ingestion. For example, Artioli et al. (2) included trained individuals (Judo athletes) and reported improvements in Wingate test performance following sodium bicarbonate ingestion. In contrast, others also included trained individuals (bicycle motocross riders) but did not observe ergogenic effects of sodium bicarbonate (22, 23). However, these studies also differed in a range of methodological characteristics—unrelated to the participants' training status—that may influence the SMD. Therefore, researchers should consider exploring the influence of training status (i.e., trained vs. untrained) on the effects of sodium bicarbonate on Wingate test performance within the same study.

A limitation of this review might be the differences in Wingate protocols used in the included studies. As summarized in Table 1, studies used different cycle ergometers (e.g., Monark, Lode Excalibur), and they also varied in the Wingate test resistance (e.g., 5% to 7.5% of individual participant body mass). While these methodological differences might explain the variation in SMDs and 95% CIs between studies, it is important to consider that the data were analyzed using the random-effects model that accounts for the inherent differences between studies that could have influenced the treatment effect (38).

Conclusion

In this review, there was no significant difference between sodium bicarbonate and placebo for mean and peak power in a single Wingate test. However, sodium bicarbonate was ergogenic for repeated Wingate performance. Specifically, there was a significant ergogenic effect of sodium bicarbonate on mean power in Wingate tests 2 and 4, and peak power in Wingate test 3. Additionally, when considering only studies that used shorter duration rest intervals, there was a significant ergogenic effect of sodium bicarbonate on mean power in Wingate test 3. Overall, these results suggest that sodium bicarbonate may provide an ergogenic effect on measures of repeated Wingate test performance.

Acknowledgment: None.

Disclosure statement: No potential conflict of interest was reported by the author.

References

1. Dennig H, Talbott JH, Edwards HT, Dill DB. Effect of acidosis and alkalosis upon capacity for work. J Clin Invest. 1931;9(4):601–13.
2. Artioli GG, Gualano B, Coelho DF, Benatti FB, Gailey AW, Lancha AH Jr. Does sodium-bicarbonate ingestion improve simulated judo performance? Int J Sport Nutr Exerc Metab. 2007;17(2):206–17.
3. Grgic J, Garofolini A, Pickering C, Duncan MJ, Tinsley GM, Del Coso J. Isolated effects of caffeine and sodium bicarbonate ingestion on performance in the Yo–Yo test: a systematic review and meta-analysis. J Sci Med Sport. 2020;23(1):41–7.
4. Grgic J, Rodriguez RF, Garofolini A, Saunders B, Bishop DJ, Schoenfeld BJ, Pedisic Z. Effects of sodium bicarbonate supplementation on muscular strength and endurance: a systematic review and meta-analysis. Sports Med. 2020;50(7):1361–75.
5. Lindh AM, Peyrebrune MC, Ingham SA, Bailey DM, Folland JP. Sodium bicarbonate improves swimming performance. Int J Sports Med. 2008;29(6):519–23.
6. Siegler JC, Hirscher K. Sodium bicarbonate ingestion and boxing performance. J Strength Cond Res. 2010;24(1):103–8.
7. Turnes T, Cruz RSO, Caputo F, De Aguiar RA. The impact of preconditioning strategies designed to improve 2000-m rowing ergometer performance in trained rowers: a systematic review and meta-analysis. Int J Sports Physiol Perform. 2019;14(7):871–9.
8. Heibel AB, Perim PHL, Oliveira LF, McNaughton LR, Saunders B. Time to optimize supplementation: modifying factors influencing the individual responses to extracellular buffering agents. Front Nutr. 2018;5:35.
9. Lancha Junior AH, Painelli Vde S, Saunders B, Artioli GG. Nutritional strategies to modulate intracellular and extracellular buffering capacity during high-intensity exercise. Sports Med. 2015;45(1):S71–81.
10. Bar-Or O. The Wingate anaerobic test. An update on methodology, reliability and validity. Sports Med. 1987;4(6):381–94.
11. Inbar O, Rotstein A, Jacobs I, Kaiser P, Dlin R, Dotan R. The effects of alkaline treatment on short-term maximal exercise. J Sports Sci 1983;1(2):95–104.
12. McCartney N, Heigenhauser GJ, Jones NL. Effects of pH on maximal power output and fatigue during short-term dynamic exercise. J Appl Physiol Respir Environ Exerc Physiol. 1983;55(1 Pt 1):225–9.

13. Parry-Billings M, MacLaren DP. The effect of sodium bicarbonate and sodium citrate ingestion on anaerobic power during intermittent exercise. Eur J Appl Physiol Occup Physiol. 1986;55(5):524–9.
14. Lopes-Silva JP, Reale R, Franchini E. Acute and chronic effect of sodium bicarbonate ingestion on Wingate test performance: a systematic review and meta-analysis. J Sports Sci. 2019;37(7):762–71.
15. Matson LG, Tran ZV. Effects of sodium bicarbonate ingestion on anaerobic performance: a meta-analytic review. Int J Sport Nutr. 1993;3(1):2–28.
16. McNaughton LR, Gough L, Deb S, Bentley D, Sparks SA. Recent developments in the use of sodium bicarbonate as an ergogenic aid. Curr Sports Med Rep. 2016;15(4):233–44.
17. Peart DJ, Siegler JC, Vince RV. Practical recommendations for coaches and athletes: a meta-analysis of sodium bicarbonate use for athletic performance. J Strength Cond Res. 2012;26(7):1975–83.
18. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. Phys Ther. 2003;83(8):713–21.
19. Grgic J, Trexler ET, Lazinica B, Pedisic Z. Effects of caffeine intake on muscle strength and power: a systematic review and meta-analysis. J Int Soc Sports Nutr. 2018;15:11.
20. Grgic J. Caffeine ingestion enhances Wingate performance: a meta-analysis. Eur J Sport Sci. 2018;18(2):219–25.
21. Higgins JPT, Deeks JJ, Altman DG, on behalf of the Cochrane Statistical Methods Group, editors. Chapter 16.1.3.2. Imputing standard deviations for changes from baseline. In: Higgins JP, Green S, editors. Cochrane handbook for systematic reviews of interventions. Version 5.1.0 (updated March 2011). Cochrane Collaboration, Chichester, UK; 2011.
22. Zabala M, Peinado AB, Calderón FJ, Sampedro J, Castillo MJ, Benito PJ. Bicarbonate ingestion has no ergogenic effect on consecutive all out sprint tests in BMX elite cyclists. Eur J Appl Physiol. 2011;111(12):3127–34.
23. Zabala M, Requena B, Sánchez-Muñoz C, González-Badillo JJ, García I, Oöpik V, Pääsuke M. Effects of sodium bicarbonate ingestion on performance and perceptual responses in a laboratory-simulated BMX cycling qualification series. J Strength Cond Res. 2008;22(5):1645–53.

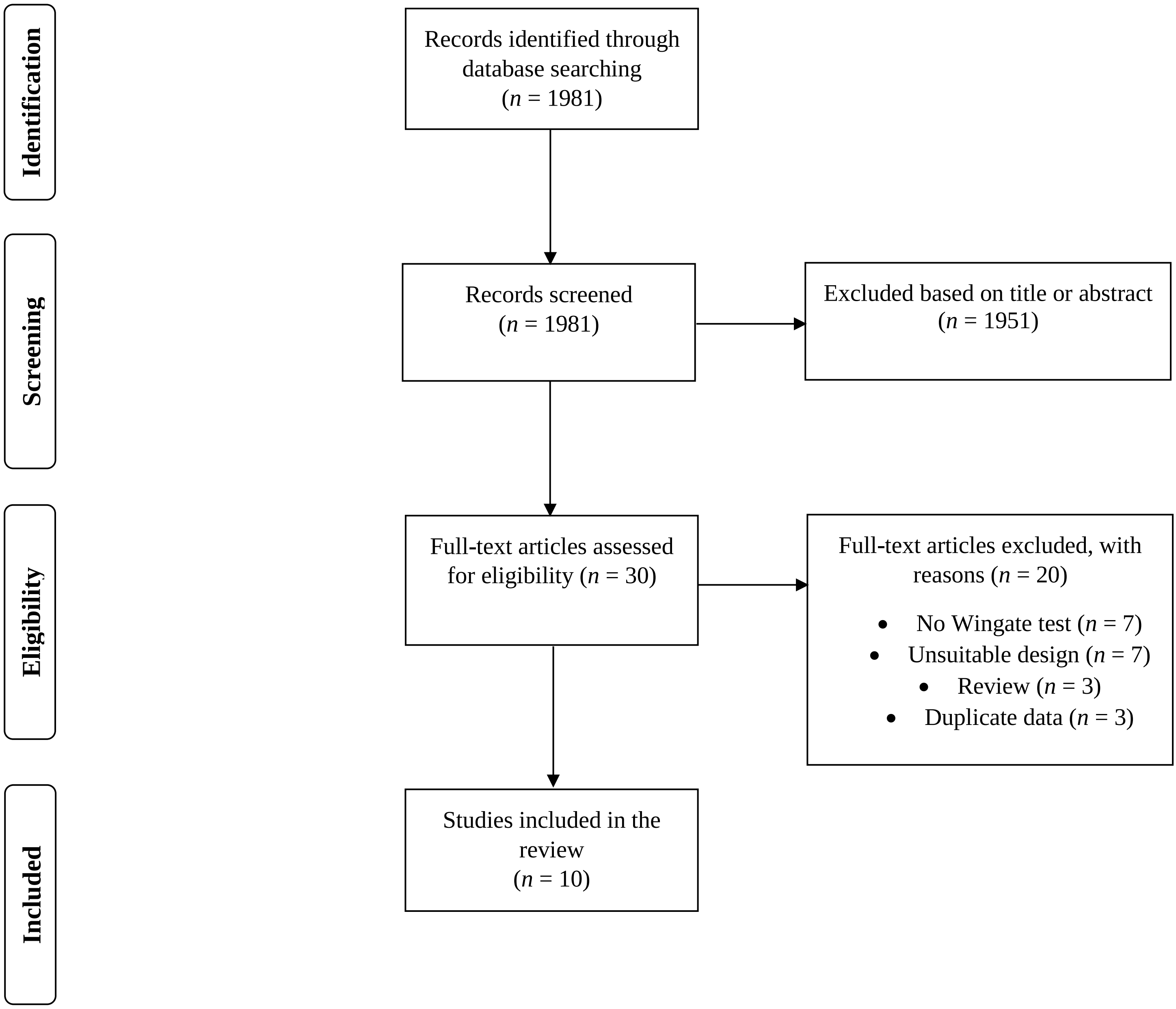
24. Crowell DJ. Influence of sodium bicarbonate upon the performance of short-duration maximal exercise of trained females. Master's thesis, University of Wisconsin-LaCrosse. 1984.
25. McNaughton LR. Sodium bicarbonate ingestion and its effects on anaerobic exercise of various durations. J Sports Sci. 1992;10(5):425–35.
26. Mündel T. Sodium bicarbonate ingestion improves repeated high-intensity cycling performance in the heat. Temperature (Austin). 2018;5(4):343–7.
27. Zinner C, Wahl P, Achtzehn S, Sperlich B, Mester J. Effects of bicarbonate ingestion and high intensity exercise on lactate and H(+)-ion distribution in different blood compartments. Eur J Appl Physiol. 2011;111(8):1641–8.
28. Bogdanis GC, Nevill ME, Boobis LH, Lakomy HK, Nevill AM. Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. J Physiol. 1995;482(Pt 2):467–80.
29. Bertucci WM, Hourde C. Laboratory testing and field performance in BMX riders. J Sports Sci Med. 2011;10(2):417–19.
30. Hofman N, Orie J, Hoozemans MJM, Foster C, de Koning JJ. Wingate test as a strong predictor of 1500-m performance in elite speed skaters. Int J Sports Physiol Perform. 2017;12(10):1288–92.
31. Watson RC, Sargeant TL. Laboratory and on-ice test comparisons of anaerobic power of ice hockey players. Can J Appl Sport Sci. 1986;11(4):218–24.
32. Hazell TJ, Macpherson RE, Gravelle BM, Lemon PW. 10 or 30-s sprint interval training bouts enhance both aerobic and anaerobic performance. Eur J Appl Physiol. 2010;110(1):153–60.
33. Saunders B, de Oliveira LF, da Silva RP, de Salles Painelli V, Gonçalves LS, Yamaguchi G, Mutti T, Maciel E, Roschel H, Artioli GG, Gualano B. Placebo in sports nutrition: a proof-of-principle study involving caffeine supplementation. Scand J Med Sci Sports. 2017;27(11):1240–7.
34. Carr AJ, Slater GJ, Gore CJ, Dawson B, Burke LM. Effect of sodium bicarbonate on [HCO3-], pH, and gastrointestinal symptoms. Int J Sport Nutr Exerc Metab. 2011;21(3):189–94.
35. Saunders B, Sale C, Harris RC, Sunderland C. Sodium bicarbonate and high-intensity cycling capacity: variability in responses. Int J Sports Physiol Perform. 2014;9(4):627–32.

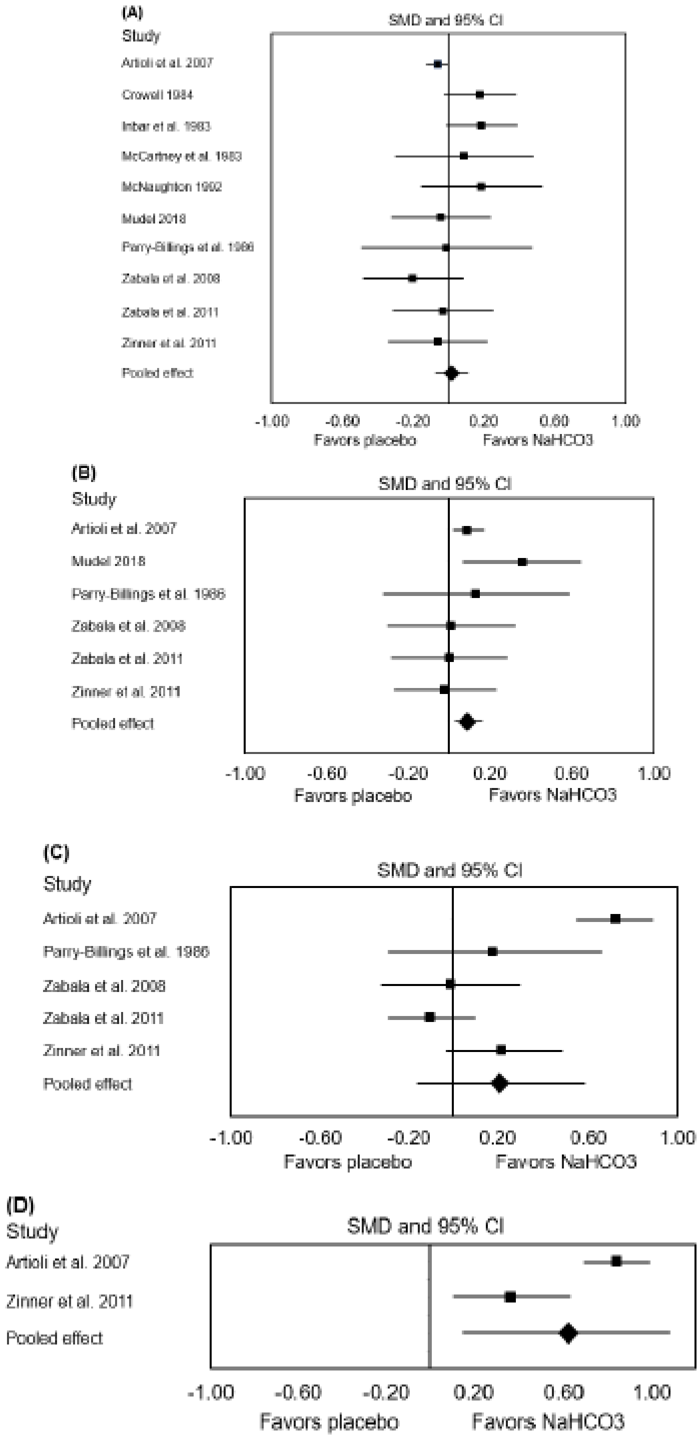
36. Mora-Rodriguez R, Hamouti N. Salt and fluid loading: effects on blood volume and exercise performance. Med Sport Sci. 2012;59:113–9.
37. Swinton PA, Hemingway BS, Saunders B, Gualano B, Dolan E. A statistical framework to interpret individual response to intervention: paving the way for personalized nutrition and exercise prescription. Front Nutr. 2018;5:41.
38. Borenstein M, Hedges LV, Higgins JP, Rothstein HR. A basic introduction to fixed-effect and random-effects models for meta-analysis. Res Synth Methods. 2010;1(2):97–111.

Figure 1. Flow diagram of the search and study selection process

Figure 2. Forest plot showing differences between the effects of placebo and sodium bicarbonate (NaHCO3) on mean power in Wingate test 1 (A), test 2 (B), test 3 (C), and test 4 (D). The numbers on the x-axis denote standardized mean differences (SMD). The horizontal lines represent the respective 95% confidence intervals (CI)

Figure 3. Forest plot showing differences between the effects of placebo and sodium bicarbonate (NaHCO3) on peak power in Wingate test 1 (A), test 2 (B), test 3 (C), and test 4 (D). The numbers on the x-axis denote standardized mean differences (SMD). The horizontal lines represent the respective 95% confidence intervals (CI)


Identification
Records identified through database searching (n = 1981)
Screening
Records screened (n = 1981)
Excluded based on title or abstract (n = 1951)
Eligibility
Full-text articles assessed for eligibility (n = 30)
Full-text articles excluded, with reasons (n = 20)
No Wingate test (n = 7)
Unsuitable design (n = 7)
Review (n = 3)
Duplicate data (n = 3)
Included
Studies included in the review (n = 10)


(A)
Study
SMD and 95% CI
Artioli et al. 2007
Crowell 1984
Inbar et al. 1983
McCartney et al. 1983
McNaughton 1992
Mudel 2018
Parry-Billings et al. 1986
Zabala et al. 2008
Zabala et al. 2011
Zinner et al. 2011
Pooled effect
-1.00 -0.60 -0.20 0.20 0.60 1.00
Favors placebo
Favors NaHCO3
(B)
Study
SMD and 95% CI
Artioli et al. 2007
Mudel 2018
Parry-Billings et al. 1986
Zabala et al. 2008
Zabala et al. 2011
Zinner et al. 2011
Pooled effect
-1.00 -0.60 -0.20 0.20 0.60 1.00
Favors placebo
Favors NaHCO3
(C)
Study
SMD and 95% CI
Artioli et al. 2007
Parry-Billings et al. 1986
Zabala et al. 2008
Zabala et al. 2011
Zinner et al. 2011
Pooled effect
-1.00 -0.60 -0.20 0.20 0.60 1.00
Favors placebo
Favors NaHCO3
(D)
Study
SMD and 95% CI
Artioli et al. 2007
Zinner et al. 2011
Pooled effect
-1.00 -0.60 -0.20 0.20 0.60 1.00
Favors placebo
Favors NaHCO3

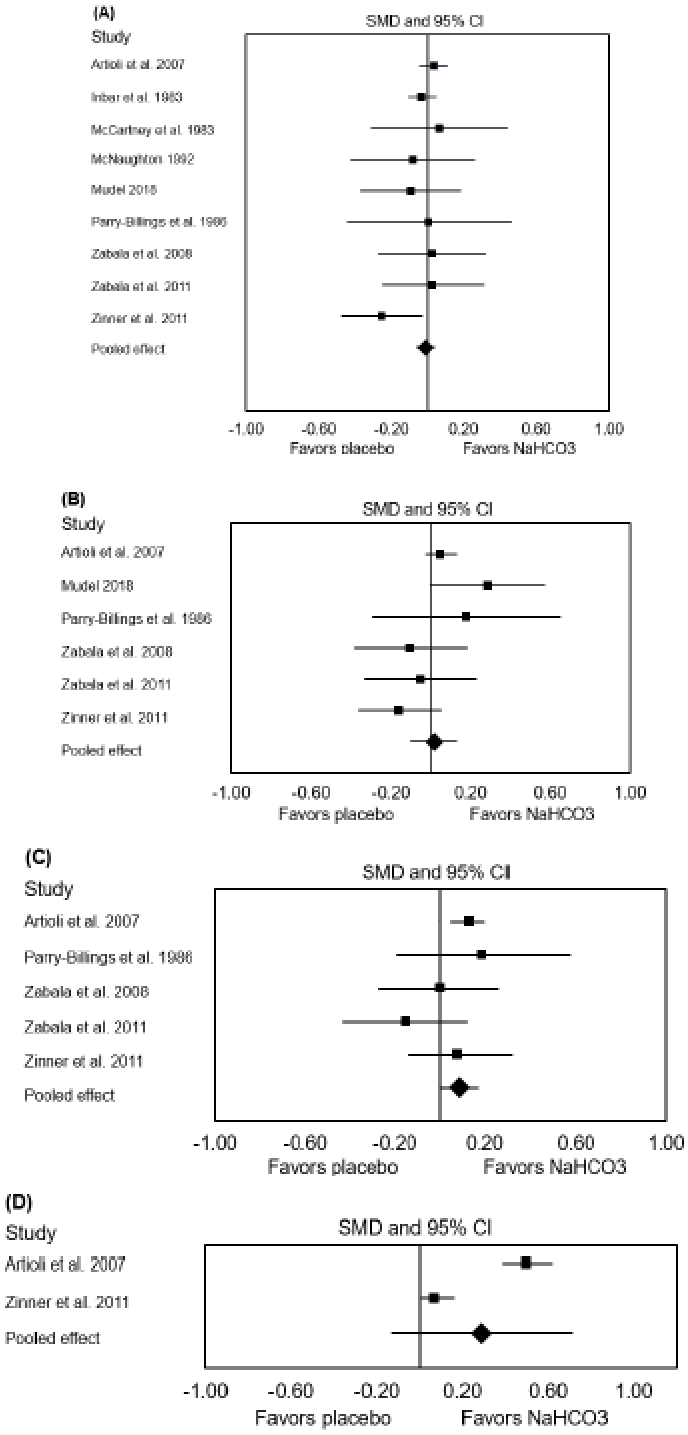

(A)
Study
SMD and 95% CI
Artioli et al. 2007
Inbar et al. 1983
McCartney et al. 1983
McNaughton 1992
Mudel 2018
Parry-Billings et al. 1986
Zabala et al. 2008
Zabala et al. 2011
Zinner et al. 2011
Pooled effect
-1.00
-0.60
-0.20
0.20
0.60
1.00
Favors placebo
Favors NaHCO3
(B)
Study
SMD and 95% CI
Artioli et al. 2007
Mudel 2018
Parry-Billings et al. 1986
Zabala et al. 2008
Zabala et al. 2011
Zinner et al. 2011
Pooled effect
-1.00
-0.60
-0.20
0.20
0.60
1.00
Favors placebo
Favors NaHCO3
(C)
Study
SMD and 95% CI
Artioli et al. 2007
Parry-Billings et al. 1986
Zabala et al. 2008
Zabala et al. 2011
Zinner et al. 2011
Pooled effect
-1.00
-0.60
-0.20
0.20
0.60
1.00
Favors placebo
Favors NaHCO3
(D)
Study
SMD and 95% CI
Artioli et al. 2007
Zinner et al. 2011
Pooled effect
-1.00
-0.60
-0.20
0.20
0.60
1.00
Favors placebo
Favors NaHCO3

Table 1. Summary of studies included in the review

Study	**Study sample**	**Sodium bicarbonate supplementation protocol**	**pH and blood bicarbonate**	**Wingate test protocol**
Artioli et al. (2007)	14 male judo competitors	0.3 $g \cdot kg^{-1}$ ingested in capsules 120 minutes before the Wingate test	Not assessed	3-minute warm-up followed by 4 upper-body Wingate tests with 3 minutes of rest between tests; resistance in the test was set at 5% of participant's body mass; ergometer model was not specified
Crowell (1984)	15 recreationally trained females	0.2 $g \cdot kg^{-1}$ ingested in a drink 60 minutes before the Wingate test	Not assessed	30-second warm-up followed by 1 lower-body Wingate test on a Monark bicycle ergometer; resistance in the test was set at 0.075 kg × participant's body mass
Inbar et al. (1983)	13 male physical education students	10 g ingested in capsules 180 minutes before the Wingate test	**pH** *Pre-exercise* Placebo: 7.37 ± 0.04 Sodium bicarbonate: 7.43 ± 0.04	6-minute warm-up followed by 1 lower-body Wingate test on a Fleisch bicycle ergometer; resistance in the test was set at 4.41 J per pedal revolution per kg of body mass
McCartney et al. (1983)	6 male participants	0.3 $g \cdot kg^{-1}$ ingested in capsules 180 minutes before the Wingate test	**pH** *Pre-exercise* Placebo: 7.40 ± 0.03 Sodium bicarbonate: 7.47 ± 0.04 **Blood bicarbonate ($mmol \cdot L^{-1}$)** *Pre-exercise* Placebo: 26.5 ± 1.1 Sodium bicarbonate: 29.3 ± 2.1	1 lower-body Wingate on a constant-velocity ergometer at a crank velocity of 100 rpm; ergometer model was not specified
McNaughton (1992)	8 male aerobically-trained participants	0.3 $g \cdot kg^{-1}$ ingested in a drink 90 minutes before the Wingate test	**Blood bicarbonate ($mmol \cdot L^{-1}$)** *Pre-supplementation* Placebo: 28.6 ± 2.8 Sodium bicarbonate: 28.3 ± 4.2	1 lower-body Wingate test on a Repco Exertech Front Access cycle ergometer; resistance was not specified

			Pre-exercise Placebo: 28.3 ± 4.0 Sodium bicarbonate: 33.9 ± 3.1	
Mudel (2018)	10 male team sport athletes	An overall dose of 0.5 g·kg^{-1} ingested in a drink at 4 hour time intervals starting 9 hours before the Wingate test	**pH** *Pre-exercise* Placebo: 7.43 ± 0.02 Sodium bicarbonate: 7.48 ± 0.03 **Blood bicarbonate (mmol·L^{-1})** *Pre-exercise* Placebo: 25.8 ± 1.1 Sodium bicarbonate: 32.9 ± 1.8	5-minute warm-up followed by 2 lower-body Wingate tests performed on a Monark bicycle ergometer with 5 minutes of rest between tests; resistance was set at 7.5% of participant's body mass
Parry-Billings and MacLaren (1986)	6 recreationally trained males	0.3 g·kg^{-1} ingested in a drink 150 minutes before the Wingate test	**pH** *Pre-supplementation* Placebo: 7.43 Sodium bicarbonate: 7.41 *Pre-exercise* Placebo: 7.38 ± 0.05 Sodium bicarbonate: 7.44 ± 0.06 **Blood bicarbonate (mmol·L^{-1})** *Pre-supplementation* Placebo: 22.1 Sodium bicarbonate: 22.2 *Pre-exercise* Placebo: 20 ± 1.9 Sodium bicarbonate: 28.7 ± 1.8	3-minute warm-up followed by 3 lower-body Wingate tests performed on a Monark bicycle ergometer with 6 minutes of rest between tests; resistance was set at 7.5% of participant's body mass
Zabala et al. (2008)	9 elite male bicycle motocross riders	0.3 g·kg^{-1} ingested in a drink 90 minutes before the Wingate test	Not assessed	10-minute warm-up followed by 3 lower-body Wingate tests performed on a Lode Excalibur bicycle ergometer with 30 minutes of rest between tests; resistance was set at 0.7 N·m·kg body mass

Zabala et al. (2011)	10 elite male bicycle motocross riders	0.3 g·kg^{-1} ingested in capsules 90 minutes before the Wingate test	**pH** *Pre-supplementation* Placebo: 7.40 Sodium bicarbonate: 7.38 *Pre-exercise* Placebo: 7.40 Sodium bicarbonate: 7.48 **Blood bicarbonate (mmol·L^{-1})** *Pre-supplementation* Placebo: 25 Sodium bicarbonate: 25 *Pre-exercise* Placebo: 25 Sodium bicarbonate: 29.5	10-minute warm-up followed by 3 lower-body Wingate tests performed on a Lode Excalibur bicycle ergometer with 15 minutes of rest between tests; resistance was set at 0.7 N·m·kg body mass
Zinner et al. (2011)	11 aerobically well-trained men	0.3 g·kg^{-1} ingested in a drink 90 minutes before the Wingate test	**Blood bicarbonate (mmol·L^{-1})** *Pre-supplementation* Placebo: 18.8 ± 2.7 Sodium bicarbonate: 19.1 ± 2.0 *Pre-exercise* Placebo: 19.3 ± 2.4 Sodium bicarbonate: 24.4 ± 2.4	4 lower-body Wingate tests performed on a Schoberer Rad Meßtechnik bicycle ergometer with 5 minutes of rest between tests; isokinetic mode was utilized, set to a cadence of 120 rpm

Table 2. Results of the methodological quality assessment using the PEDro checklist

Reference	**Item 1**	**Item 2**	**Item 3**	**Item 4**	**Item 5**	**Item 6**	**Item 7**	**Item 8**	**Item 9**	**Item 10**	**Item 11**	**Total score**
Artioli et al. (2007)	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
Crowell (1984)	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Inbar et al. (1983)	No	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
McCartney et al. (1983)	No	Yes	Unclear	Yes	Unclear	Unclear	Unclear	Yes	Yes	Yes	Yes	6
McNaughton (1992)	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Mudel (2018)	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Parry-Billings and MacLaren (1986)	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Zabala et al. (2008)	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Zabala et al. (2011)	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Zinner et al. (2011)	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Yes: criterion is satisfied; No: criterion is not satisfied; Unclear: unable to rate												