EFECTOS AGUDOS DE LA SUPLEMENTACIÓN CON BICARBONATO DE SODIO EN EL RENDIMIENTO DEL EJERCICIO DE FUERZA CON FINES DE HIPERTROFIA: UNA REVISIÓN SISTEMÁTICA.

ACUTE EFFECTS OF SODIUM BICARBONATE SUPPLEMENTATION ON HYPERTROPHY-TYPE RESISTANCE EXERCISE PERFORMANCE: A SYSTEMATIC REVIEW.

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Resumen

Introducción:

La suplementación con bicarbonato sódico ($NaHCO_3$) se asocia con un mayor rendimiento en el ejercicio físico de alta intensidad, al evitar la excesiva acidez muscular y aumentar la capacidad de mantener el equilibrio ácido-base durante el ejercicio. Sin embargo, los efectos de la suplementación con bicarbonato sódico en el entrenamiento de fuerza con fines de hipertrofia no están claros.

Objetivo:

Evaluar los efectos agudos de la ingesta de bicarbonato sódico en el rendimiento del ejercicio de fuerza con fines de hipertrofia, y en parámetros sanguíneos relacionados con la fatiga.

Métodos:

La presente búsqueda se hizo siguiendo la declaración PRISMA en las bases de datos Medline/PubMed y Scopus hasta marzo de 2022. No se aplicaron filtros por sexo, edad o experiencia en el entrenamiento de fuerza. El rendimiento en ejercicios de fuerza con fines de hipertrofia se evaluó mediante los cambios en el número de repeticiones en ejercicios de fuerza o un mayor trabajo realizado en los protocolos isocinéticos antes del fallo muscular. Además, se examinaron parámetros sanguíneos ácido-base estrechamente relacionados con la fatiga muscular y el rendimiento (pH y lactato).

Resultados:

Se incluyeron 10 estudios de diseño cruzado que evaluaban los efectos de la ingesta de bicarbonato sódico frente a placebo en varias tareas de ejercicio de fuerza con fines de hipertrofia. Los resultados parecen indicar que la ingesta de bicarbonato sódico puede aumentar de forma aguda el rendimiento en el ejercicio de hipertrofia y conduciría a mayores concentraciones de pH y lactato tras el ejercicio.

Conclusión:

La suplementación con bicarbonato sódico puede inducir efectos ergogénicos agudos en el rendimiento del ejercicio de fuerza con fines de hipertrofia. Además, se lograría un mejor ambiente ácido-alcalino en base a los efectos sobre las concentraciones en sangre de pH y lactato. Se necesita más investigación en estudios longitudinales y basados en mujeres.

Abstract

Introduction:

Sodium bicarbonate ($NaHCO_3$) supplementation is associated with enhanced performance in high-intensity physical exercise, by avoiding excessive muscle acidity and increasing the capacity to maintain an acid-base balance during exercise. However, the effects of sodium bicarbonate supplementation on resistance training with hypertrophy purpose are not clear.

Objective:

To assess the acute effects of sodium bicarbonate ingestion on hypertrophy-type resistance exercise performance, and on blood parameters related to fatigue.

Methods:

The current search was conducted following the PRISMA statement in the Medline/PubMed and Scopus databases until March, 2022. No filters for gender, age, or resistance training experience were applied. Hypertrophy-type resistance exercise performance was assessed by changes in the number of repetitions on resistance exercises or greater work in isokinetic protocols before muscle failure. Furthermore, blood acid-base parameters closely related to muscle fatigue and performance (pH and lactate) were examined.

Results:

10 cross-over studies design assessing the effects of sodium bicarbonate ingestion versus placebo on various resistance exercise tasks for hypertrophy purposes were included. The results seem to indicate that sodium bicarbonate ingestion may acutely increase performance in hypertrophy exercise and would lead to greater post-exercise pH and lactate concentrations.

Conclusion:

Sodium bicarbonate supplementation may induce acute ergogenic effects on hypertrophy-type resistance exercise performance. In addition, a better acid-alkaline environment would be achieved based on the effects on blood pH and lactate concentrations. Further research is needed in longitudinal and female-based studies.

Índice

1. Introduction

Muscle hypertrophy refers to an increase in the size of muscle tissue and occurs when exercise-induced protein synthesis rates exceed protein degradation (Schoenfeld & Grgic, 2018). Continuous performance of resistance training is well established as the most effective exercise intervention to achieve hypertrophy (Krzysztofik et al., 2019; Schoenfeld et al., 2015). This type of training is mainly used by bodybuilders or people looking for an aesthetic improvement of their body by gaining muscle mass. In addition, it would have a great application to improve performance in athletes such as powerlifters, weightlifters, rugby or football players and in the diseases prevention or rehabilitation of sports injuries (Sartori et al., 2021; Schoenfeld, 2010; Taber et al., 2019).

There are different types of training protocols related to resistance training with muscle hypertrophy aims. Both performing several sets to muscle failure or close to it in a range of 8-12 repetitions (reps) and performing sets with fewer repetitions (3-6) and higher load are approved methods to achieve hypertrophy (Klemp et al., 2016; Kubo et al., 2021; Schoenfeld et al., 2014). Furthermore, the use of isokinetic training methods, has also been contrasted to achieve muscle development (Ghroubi et al., 2016; Horwath et al., 2019; Matta et al., 2017).

The performance of hypertrophy-type resistance training can be improved by following the ingestion of supplements which represent an ergogenic aid, such as sodium bicarbonate ($NaHCO_3$), becoming recognise in 2018 as a safe and effective supplement by the International Olympic Committee (Maughan et al., 2018; Moriones & Santos, 2017). Sodium bicarbonate is a substance produced naturally in the kidneys, and it might have an important role in sports performance, avoiding excessive muscle acidity and achieving a balance in the alkaline environment of human physiology during exercise (Carr et al., 2011; Lancha Junior et al., 2015). However, the quantities of sodium bicarbonate produced naturally by human body would be insufficient to support sporting performance, and according to Heibel et al., (2018) and Grgic et al., (2021) an additional intake of 0.2 to 0.3 g/kg^{-1} between 60 and 180 min before exercise would be necessary in order to achieve an ergogenic effect in tasks such as combat sports and high-intensity cycling, running and swimming.

There is a strong evidence that support the ergogenic effects of sodium bicarbonate supplementation in high-intensity physical exercise such as swimming, cycling, and repeated-sprint performance (Dalle et al., 2021; Grgic, Garofolini, et al., 2020; Gurton et al., 2020; Lindh et al., 2008; Lopes-Silva et al., 2019; Siegler & Hirscher, 2010). Specifically, the higher effects of sodium bicarbonate ingestion would be observed in high intensity tasks with high anaerobic metabolic demand that lasts between 30 seconds -12 minutes (Grgic et al., 2021; Heibel et al., 2018; Lancha Junior et al., 2015). Therefore, the different protocols for hypertrophy training would fall within these aforementioned anaerobic demands whereby bicarbonate would have an effect on performance. Supplementation with sodium bicarbonate would increase bicarbonate concentrations in the blood, thus causing a "buffering" effect, a physiological mechanism which would aid to maintain an acid-base balance, a factor highly associated with delaying muscle fatigue in resistance exercise (Fitts, 2016; Lancha Junior et al., 2015). Due to this alteration in the body's alkalotic environment, several blood acid-base parameters related to fatigue and performance, such as pH and lactate [Lac−], may be altered (Carr et al., 2011; Carr et al., 2013). Consequently, an improvement in performance could be obtained by achieving a higher number of repetitions on resistance exercise protocols or greater work in isokinetic protocols before muscle failure (La Scala Teixeira et al., 2019).

Webster et al., (1993) examined the effects of bicarbonate intake in resistance exercise with hypertrophy methods, by performing 4 sets of 12 repetitions, with the addition of an additional last set taken to muscle failure on a leg press machine, in which 4 of the 6 participants performed a greater volume of work (repetitions), but without obtaining statistically significant results. Nonetheless, other authors reported a significant improvement in performance in the squat, leg press and knee extension exercises, based on a significant increase in repetitions after sodium bicarbonate ingestion in contrast to the placebo group (Carr et al., 2013).

Although there are several systematic reviews that have examined the acute effects of sodium bicarbonate intake on various exercise performance tasks (Carr et al., 2011; Grgic et al., 2020; Hadzic et al., 2019; Lopes-Silva et al., 2019), none of them is specialised solely in resistance training and more specifically in training aimed at muscle mass gains. Grgic, et al., (2020) assessed the effects of sodium bicarbonate on muscular endurance by including studies in which some of the protocols consisted of resistance exercises, but also included studies whose protocols were not associated with hypertrophy purpose, such as specific anaerobic tests, stationary bike tests or isometric exercises. Therefore, the aim of this study was to critically review studies that assessed the acute effects of sodium bicarbonate supplementation on the performance of resistance exercise with appropriate training protocols for hypertrophy. Furthermore, the variations caused by sodium bicarbonate supplementation on parameters related to fatigue, were examined as a secondary objective.

2. Methods

2.1 Literature Search

This systematic review was designed and conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines (Page et al., 2021). For this purpose, studies published prior to March, 2022 were examined. PubMed/MEDLINE and Scopus databases were reviewed, using the following search syntax for Pubmed: (("sodium bicarbonate"[Title/Abstract] OR "NaHCO3"[Title/Abstract] OR "induced alkalosis"[Title/Abstract])) AND (("muscle endurance"[Title/Abstract] OR "muscular endurance"[Title/Abstract] OR "hypertrophy-type resistance exercise"[Title/Abstract] OR "resistance exercise"[Title/Abstract] OR "strength training"[Title/Abstract] OR "resistance training"[Title/Abstract] OR "isokinetic"[Title/Abstract]) OR ("torque"[Title/Abstract] OR "repetitions to failure" "total repetitions"[Title/Abstract] OR "fatigue"[Title/Abstract]) OR ("bench press"[Title/Abstract] OR "squat"[Title/Abstract] OR "knee extension"[Title/Abstract] "knee extension")). The search in Scopus were performed as follow: TITLE-ABS-KEY ((("sodium bicarbonate" OR "NaHCO3" OR "induced alkalosis")) AND (("muscle endurance" OR "muscular endurance" OR "hypertrophy-type resistance exercise" OR "resistance exercise" OR "strength training" OR "resistance training" OR "isokinetic") OR ("torque" OR "repetitions to failure" "total repetitions" OR "fatigue") OR ("bench press" OR "squat" OR "knee extension"))). In addition, Google Scholar and Research Gate was used for conducting a general search for studies examining resistance training and sodium bicarbonate supplementation which were not included in the databases mentioned before. Secondary searches were conducted by reviewing the references of the included studies and studies that cited these same studies. No publication date restrictions were applied only articles available in full text were considered. The search was performed on March 24, 2022.

2.2 Inclusion Criteria

Studies were included in this review if they meet the following criteria:(i) employed a cross-over study design to address the effects of a pre-exercise intake of sodium bicarbonate on resistance exercise performance following hypertrophy validated protocols; ii) published in English; iii) studies that included healthy humans as participants. In order to consider specific protocols for hypertrophy, studies were only accepted whether used sets of hypertrophy-type endurance exercises aiming to perform the maximum number of repetitions at a given load or total isokinetic work. In addition, as a secondary objective, changes in pH and lactate [Lac-], blood acid-base parameters closely related to muscle fatigue and performance, were examined in those main studies that assessed them.

Studies were excluded when: (i) studies that combine sodium bicarbonate supplementation with other ergogenic aids (i.e. caffeine or beta-alanine); (ii) studies with lack of detailed description in the training protocol; (iii) use of non-hypertrophy related training protocols. Therefore, studies which assessed the effects of sodium bicarbonate ingestion on sets of non-hypertrophy related exercise protocols such as isometric exercise, aerobic tasks or anaerobic specific tests (Wingate Test / Running-Based Anaerobic Sprint Test) were not included for this review.

The following criteria were outlined in the Participant-Intervention-Comparison-Outcome (PICO) process: (Eriksen & Frandsen, 2018).

- Participants: healthy individuals, not limited to age or experience in resistance training.
- Intervention: sodium bicarbonate ingestion.
- Comparison: placebo group or control group.
- Outcome measures: hypertrophy-type resistance exercise performance (total repetitions or total isokinetic work) and/or changes in some parameters regarding to muscular fatigue and performance (blood pH and lactate).

2.3 Data extraction

For each of the included studies, the following data were extracted: (a) author(s) and year of publication; (b) sample size and participant's characteristics, including sex and resistance training experience; (c) details of the hypertrophy-type resistance training protocol or task(s); (d) sodium bicarbonate supplementation protocols (dose and timing); (e) blood pH and lactate values before and after ingestion or supplementation of sodium bicarbonate and placebo; (f) reported side effects and (g) main findings regarding hypertrophy performance outcomes.

2.4 Methodological quality

Risk of bias and methodological quality of the included studies were assessed, using the Quality assessment standard for a cross-over study scale (Ding et al., 2015). The scale consists of a checklist composed of nine standard items to evaluate the risk of bias, which are evaluated as high, unclear or low risk of bias. These items assess a possible risk of bias in: (1) appropriate cross-over design; (2) the randomized order of treatment receipt; (3) carry-over effects; (4) unbiased data; (5) allocation concealment; (6) blinding; (7) incomplete outcome data; (8) selective outcome reporting; and (9) other biases.

3. Results

3.1 Study selection

Table 1 provides the details of the included studies. Following the primary literature search, a total of 132 potentially relevant references were identified. From these results, 22 of them were removed because they were duplicative. From the remaining 110 studies screened, 91 were excluded based on title or abstract, 19 full-text papers were read and only 9 studies were included as they met the full set of inclusion criteria. The main reasons for exclusion were: i) realisation of a non-optimal training protocol for hypertrophy (n = 7); ii) use of electrical stimulation for potentiation (n = 2); iii) non-intake of sodium bicarbonate (n = 1). The secondary searches resulted in another 26 search results, of which 1 additional study was included in the review. Therefore, the final number of included studies was 10 (Figure 1).

3.2 Study Characteristics

The included randomized controlled studies comprised 103 participants (Table 1). The average sample size for each included study was 10 participants and the average age of all the participants was 23.16. All studies counted as male participants, except for a unique study that included 2 women. In 8 of the 10 included studies (Carr et al., 2013; Duncan et al., 2014; Fontanella et al., 2020; Lima et al., 2020; Materko et al., 2008; Portington et al., 1998; Siegler et al., 2018; Webster et al., 1993), the participants were trained subjects with 1 or 2 years' experience in resistance training. In another study (Coombes &

McNaughton, 1993), the subjects were physical education students with regular practice in sports but not in strength or resistance training, and in the remaining cross-over trial participants were college students. In all studies included in this review a dose of 0.3 g kg^{-1} $NaHCO_3$ in liquid or capsule form and the time of intake ranged from 30 to 180 minutes prior to exercise.

3.3 Methodological quality

A summary of the methodological quality assessment of the primary studies of this systematic review are shown in Table 2. Overall, nearly all studies had a low risk of bias for most of the items assessed. However, the results for items 3 and 5, which assess the carry-over effect and allocation concealment respectively, were unsure for all studies, as it was difficult to judge these items.

3.4 Effects of sodium bicarbonate supplementation on hypertrophy-type resistance exercise performance

10 experimental trials explored the effects of sodium bicarbonate on the responses in performance on hypertrophy-type resistance exercise (Table 1). In mostly of them, the performance task included exercise-based tasks or protocols of different sets until failure of traditional resistance exercises such as bench press, back squat and leg extension, all of which were considered appropriate to be performed as part of a planned exercise programme for the purpose of muscle hypertrophy. Moreover, of these studies, 2 conducted an isokinetic training protocol. In both, the exercise task consisted of knee flexion and extension on an isokinetic leg extension machine. Performance in these physical tasks was evaluated either by the number of repetitions, by lifting heavier weight for a given number of repetitions or by the total work (flexion and extension) performed in the case of isokinetic exercise. Regarding to supplementation protocol, in all included studies, following a cross-over design, participants were randomly assigned to complete a hypertrophy resistance exercise protocol under 2 different treatment trials in a blindly manner: 0.3 g kg^{-1} of $NaHCO_3$ and placebo. In almost all studies, for the placebo condition, 0.3 g kg^{-1} of calcium carbonate ($CaCO_3$) was administered. However, in 3 of the studies (Duncan et al., 2014; Fontanella et al., 2020; Materko et al., 2008), it was administered 0.045 $g \cdot kg^{-1}$ of sodium chloride solution (NaCl). Conversely, Portington et al., (1998) and Webster et al., (1993) administered 0.3 g kg^{-1} of white flour. Regardless of the different solutions ingested, the exercise protocol task was identical and the timing for the different supplementation, either with sodium bicarbonate or placebo was the

same, ranging from 30 to 180 minutes prior to exercise. Some studies supplied sodium bicarbonate in a liquid form whether others opted for inherit it in a capsule form, also the dosage distribution of sodium bicarbonate was different, as some studies provided it at a single time point, while other studies divided the total dose and administered it at multiple time points.

In 4 studies of this review, significant differences between sodium bicarbonate and placebo were found in the number of repetitions or total work performed in at least one of the exercises for each of the training protocols chosen for each study. In Duncan et al., (2014) study, it is showed that after sodium bicarbonate intake, participants were able to perform significantly more repetitions in the squat ($NaHCO_3$: 31.3 reps ± 15.3, placebo: 24.6 reps ± 16.2; $p = 0.04$) but for the bench press, performed immediately afterwards, the increase in the number of repetitions was not significant ($NaHCO_3$: 28.7 reps ± 12.2, placebo: 26.7 reps ± 10.2; $p = 0.679$). In this line, Carr et al., (2013) found significant differences in the number of total repetitions after a hypertrophy training protocol to failure, including squat, leg press and leg extension, performed 60 minutes after sodium bicarbonate or placebo supplementation ingestion ($NaHCO_3$: 139.8 reps ± 13.2, placebo: 134.4 reps ± 13.5; $p <0.05$). Fontanella et al., (2020) after performing a hypertrophy session protocol with 3 exercises (bench press, machine chest fly and triceps pushdown), found that after the intake of sodium bicarbonate the participants performed significantly more repetitions in machine chest fly ($p = 0.04$), and a greater number of total repetitions was achieved for the whole exercise session, but not significantly ($NaHCO_3$: 92.43 reps ± 10.43, placebo: 91.71 reps ± 8.91; $p = 0.847$). Lima et al., (2020) and Webster et al., (1993) assessed hypertrophy exercise performance by performing 8 sets to failure in the extensor chair and direct thread, and by performing one set of leg press to failure respectively. In both instances, they found a higher number of repetitions completed after sodium bicarbonate ingestion, but not significantly (NaHCO3: 67.70 reps ±15.59, placebo: 64.60 reps ±10.61; p= 0.61) (NaHCO3: 19.6 reps ±1.6; placebo: 18.2 reps ±1.1; p= 0,29).

Regarding isokinetic exercise protocols, Coombes & McNaughton, (1993) found significant differences in greater work (Kj) performed in isokinetic leg flexion and extension after sodium bicarbonate ingestion ($NaHCO_3$: 10.756 Kj ± 1.441, placebo: 10.096 Kj ± 1.393; $p <0.05$); while Balberman, (1983) reported greater but non-significant work (flexion + extension) performed in the same exercise, but performed for one-legged ($NaHCO_3$: 733 Kj ± 142, placebo: 723 Kj ± 136, control: 728 Kj ± 150; $p > 0.05$).

In the remaining included studies (Materko et al., 2008; Portington et al., 1998; Siegler et al., 2018), no effect of sodium bicarbonate supplementation on hypertrophy exercise performance was found.

3.5 Effects of sodium bicarbonate supplementation on fatigue related parameters

In all included studies with the exception of 2 (Fontanella et al., 2020; Materko et al., 2008), changes in pH, [Lac-] or both were assessed (Table 1). Specifically, the values of the two parameters mentioned above were measured at rest, before exercise and after exercise, both after sodium bicarbonate and placebo ingestion.

Carr et al., (2013) reported sodium bicarbonate ingestion leaded to significantly higher [Lac−] concentration after the exercise protocol (NaHCO3: 17.92 ± 2.08 mM, placebo: 15.55 ± 2.50 mM; $p < 0.05$). Likewise, Coombes & McNaughton, (1993) also found significantly higher lactate concentration after performing isokinetic leg flexion and extension. In the same way, some studies despite non finding significant effects in performance, found significant physiological differences post exercise in pH and [Lac−] concentrations. For instance, Portington et al., (1998) did not find differences in the number of possible repetitions to failure in the leg press machine ($NaHCO_3$: 59 reps ± 3, placebo: 60 reps ± 2; $p > 0.05$), however they obtained that pH and lactate concentrations post-exercise were significantly higher after sodium bicarbonate ingestion (pH: $NaHCO_3$: 7.33; -placebo: 7.26; [Lac−] - $NaHCO_3$: 13.4 Mm; placebo:11.3 mM). Webster et al., (1993) also found significantly lower pH during exercise after sodium bicarbonate intake ($NaHCO_3$: 7.32 ± 0.02, placebo: 7.25 ± 0.02).

In the remaining studies (Balberman, 1983; Duncan et al., 2014; Lima et al., 2020; Siegler et al., 2018), higher post-exercise concentrations of pH, lactate or both were reported, but in this case the differences between sodium bicarbonate and placebo were not significant.

4. Discussion

To the best of our knowledge, this is the first systematic review assessing the effects of sodium bicarbonate supplementation on the performance of resistance exercise with appropriate training protocols for hypertrophy.

The findings of this systematic review suggest that sodium bicarbonate supplementation may induces acute ergogenic effects on hypertrophy exercise performance and leads to greater post-exercise pH and lactate concentrations**.** Sodium bicarbonate ingestion might increase the number of repetitions performed at an appropriate range of reps for hypertrophy (3-15) and perform higher isokinetic work.

4.1 Effects of sodium bicarbonate supplementation on hypertrophy-type resistance exercise performance

Hypertrophy- type resistance exercise performance in this review was assessed in order to examine possible ergogenic effects on performance. 4 studies in this review found significant differences with regard to the number of repetitions until failure or isokinetic total work performed (Carr et al., 2013; Coombes & McNaughton, 1993; Duncan et al., 2014; Fontanella et al., 2020). In contrast to Coombes & McNaughton, (1993) trial, in which isokinetic protocol work was performed, the other 3 studies mentioned above carried out an hypertrophy training protocol with different exercises: global exercises (bench press or squat) and analytical exercises (quadriceps extension), and each study obtained different results in which the effect of sodium bicarbonate ingestion was not found to be greater in one type of exercise than in others. Therefore, contrary to our expectations, although global exercises such as a squat or bench press demand a greater involvement of muscle groups and involve greater fatigue, they were not favoured to obtain a greater ergogenic response from sodium bicarbonate ingestion in comparison with more analytical exercises.

Carr et al., (2013) found significant differences in the number of total repetitions after a hypertrophy to failure training protocol including squat, leg press and leg extension, however Portington et al., (1998) and Webster et al., (1993), who also performed a hypertrophy lower-body exercise protocol including leg press, dis not found significant differences in the number of repetitions. These different results can be explained as Carr et al., (2013) employed a longer exercise protocol with more exercises and higher intensity, whereas Portington et al., (1998) and Webster et al., (1993) employed exclusively a 5 set protocol and only 1 set to exhaustive failure was performed in Webster et al., (1993) study. Following this approach, Materko et al., (2008) also did not found ergogenic effects on maximal repetitions on the bench press and on the pull press. In that study, the protocol exercise that was used consisted only on a unique set for each exercise. Conversely, Fontanella et al., 2020), in which participants also performed an upper body exercise protocol including bench press exercise among other, at least reported significantly greater repetitions in one of the exercises performed in the overall protocol. In contrast to Materko et al., (2008), it was performed a protocol with higher volume and which demanded higher intensity.

Balberman, (1983) and Coombes & McNaughton, (1993), performed a resistance exercise protocol on isokinetic leg flexion and extension, but while Coombes & McNaughton, (1993) reported significantly more isokinetic work, Balberman, (1983) did not found signicant differences in the same exercise task. These diferences might be explained due to Balberman, (1983) employed shorter protocol in which only consisted on 1 set of knee flexion and extension work for one-legged for 1 minute and perhaps that exercise bout might be insufficient to show the changes caused by alkalosis and buffering capacity after sodium bicarbonate ingestion. Once again, as in the previous comparison, significantly effects of sodium bicarbonate were seen in those studies that performed a higher volume exercise protocol and at a higher intensity. Therefore, the justification that might explained that some studies did not found effects of sodium bicarbonate on performance, might be lead due to an insufficient volume or intensity protocol exercise. In that case, the acid-base alterations caused by that amount of exercise would not be sufficient to establish a pH gradient strong enough to facilitate the outflow of intracellular hydrogen ion (H+) from the cell into the extracellular medium, caused by alkalosis and buffering capacity after sodium bicarbonate ingestion (Matson & Tran, 1993).

According to what has been explained above, it would be difficult to see an improvement in the number of repetitions or isokinetic work after a single task or set at high intensity. It is showed in Duncan et al., (2014) study, in which significantly higher number of repetitions in the back squat were found in the last two sets performed, but not on the first. However, none effects for bench press repetitions were found, performed inmediatly after back squat. This would suggest that the effects of sodium bicarboante might be limited and short-lived, as the effects of accumulated fatigue caused by performing sets to failure would diminish any ergogenic effect.

The acute effect in performance in the studies showed above could be explained by the fact that supplementation with sodium bicarbonate would increase bicarbonate concentrations in the blood, thus causing an enhancement of the extracellular "buffering” capacity, a physiological mechanism which would help to maintain an acid-base balance, and consequently delay the onset of muscular fatigue (Fitts, 2016; Lancha Junior et al., 2015). In high-intensity physical exercise with short rest periods, the anaerobic metabolic pathway, also called glycolytic, produce adenosine triphosphate (ATP) from glucose in order to sustain exercise, in addition to lactate (Robergs, 2017). Lactate participates to buffer H+ ions , which originate as a consequence of glycolysis (Bangsbo et al., 1993; Robergs et al., 2004). However, as training progresses, the amount of H+ ions exceed the production of lactate, reducing the buffering capacity and leading into an accumulation of intracellular H+ and a reduction in pH, generating acidosis in the organism (Fitts, 2016; Sahlin, 1992). Acidosis would inhibit glycolysis, resulting in a reduction in force production due to the onset of fatigue Robergs, 2017; Sahlin, 1992). In this way, sodium bicarbonate supplementation, by increasing sodium bicarbonate levels in the blood, would act as a buffer, reducing H+ levels and increasing pH, allowing a greater acid-base balance destabilised during exercise (Grgic et al., 2021). This would lengthen the time to fatigue and allow greater ATP production, which could result in improved performance (Grgic et al., 2021; Lancha Junior et al., 2015). By improving performance, enhanced training adaptations such as greater muscle stimulation might be achieved which could result in greater muscle hypertrophy.

4.2 Effects of sodium bicarbonate supplementation on fatigue related parameters

For this review, pH and lactate, blood acid-base parameters related to fatigue and performance, were examined. It were found 6 studies assessing basal, pre- and post-exercise pH levels in both the placebo and experimental groups. Balberman, (1983); Carr et al., (2013); Duncan et al., (2014); Portington et al., (1998) and Webster et al., (1993) reported a higher post-exercise pH concentration after sodium bicarbonate supplementation, with the difference being significant in 2 of them (Portingon et al., 1998; Webster et al., 1993). As a consequence of using the glycolytic energy pathway, H+ is generated, in addition to lactate, which helps to buffer H+ ions (Robergs et al., 2004). However, over the course of training, H+ concentrations increase, causing a reduction in pH levels (acidosis) and inhibiting glycolysis, leading to fatigue (Lancha Junior et al., 2015). Nevertheless, as explained above, through the sodium bicarbonate intake, a lower reduction in pH may be achieved, as a consequence of a higher buffering capacity and a reduction in H+ concentration (Grgic et al., 2021).

Regarding to blood lactate, six included studies reported higher lactate concentration post-exercise after sodium bicarbonate ingestion, with significant differences compared to the placebo group in three of them (Carr et al., 2013; Coombes & McNaughton, 1993; Portington et al., 1998) . A higher lactate concentration might be explained as due to the metabolic alkalosis achieved with sodium bicarbonate ingestion, more anaerobic work and energy production (ATP) would be performed before reaching fatigue, and this would lead to a higher production of lactate by glycolysis (Carr et al., 2013).

In all studies of this review, 0.3 g kg^{-1} of sodium bicarbonate (NaHCO3) was administered either in liquid or capsule form and the time of intake ranged from 30 to 180 minutes prior to exercise. These quantities are safe for the body, but it may lead to some side effects in some people such as nausea, stomach pains (Carr et al., 2011; Froio de Araujo Dias et al., 2015; Saunders et al., 2014). The incidence and seriousness of side effects vary within individuals, but these effects are mild in general. However, it should be considered that these side effects may limit an improvement in performance, especially in people susceptible to gastrointestinal problems; but overall, these side effects do not seem to outweigh the potential performance improvements. Various nutritional strategies such as taking sodium bicarbonate in several small doses, taking it in capsules, or ingesting it with carbohydrate beverage could minimise the likelihood and severity of these side effects (Carr et al., 2013; Grgic et al., 2021; Hilton et al., 2019).

The key strengths of this systematic review are: (i) following PRISMA statement for systematic reviews, (ii) the use of a specific risk of bias scale for studies with a cross-over design, (iii) the application of a standardised inclusion criteria. The main limitation of this review is the paucity of studies carried out in relation to NaHCO3 ingestion and hypertrophy-type resistance exercise performance. This issue forced us to pool studies with different resistance training backgrounds., sexes, and different hypertrophy protocols, either with low and high exercise volume. In fact, some studies carried out a hypertrophy training protocol by performing some sets in a single exercise, whether other performed more than 1 exercises. Another limitation of these systematic review is that, of the total of 103 participants included in the primary studies, only 2 were females.

Therefore, future studies are warranted to explore the effects of sodium bicarbonate supplementation in women on resistance training for hypertrophy purposes.

Given that sodium bicarbonate ingestion appears to acutely increase performance in hypertrophy exercise, are needed more studies that explore sodium bicarbonate effects exclusively on high volume hypertrophy training protocol. In this way, it could be determined whether performance effects occur in a regular hypertrophy exercise routine, as in this review those studies with a higher volume exercise protocol reported some positive effect of $NaHCO_3$ ingestion. A further possible line of research could be to explore whether the effects of chronic supplementation could enhance the adaptations inherent in hypertrophy training, such as muscle mass gain.

5. Conclusion

Our findings indicate that sodium bicarbonate supplementation may induce acute ergogenic effects on hypertrophy-type resistance exercise performance. Moreover, it seems that a better acid-alkaline environment would be achieved based on the effects on blood pH and lactate concentrations. The extent of this acute ergogenic effect would be unrelated to either the size of the muscle groups involved or the distribution of doses, either at one or multiple intake time points. Therefore, athletes such as powerlifters, weightlifters, rugby or football players who perform hypertrophy training in their training schedule, as well as bodybuilders and people looking for aesthetic enhancement, may consider sodium bicarbonate supplementation.

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None

Conflicts of Interest

None

6. References

Balberman, S. E. (1983). The effects of induced alkalosis and acidosis on the work output of the knee extensor and flexor muscle groups. *Item Type text; Thesis-Reproduction (electronic)*. Retrieved April 15, 2022, from http://hdl.handle.net/10150/274719

Bangsbo, J., Johansen, L., Graham, T., & Saltin, B. (1993). Lactate and H+ effluxes from human skeletal muscles during intense, dynamic exercise. *The Journal of Physiology*, *462*(1), 115–133. https://doi.org/10.1113/jphysiol.1993.sp019546

Carr, A. J., Hopkins, W. G., & Gore, C. J. (2011). Effects of Acute Alkalosis and Acidosis on Performance. *Sports Medicine*, *41*(10), 801–814. https://doi.org/10.2165/11591440-000000000-00000

Carr, A. J., Slater, G. J., Gore, C. J., Dawson, B., & Burke, L. M. (2011). Effect of Sodium Bicarbonate on [HCO3−], pH, and Gastrointestinal Symptoms. *International Journal of Sport Nutrition and Exercise Metabolism*, *21*(3), 189–194. https://doi.org/10.1123/ijsnem.21.3.189

Carr, B. M., Webster, M. J., Boyd, J. C., Hudson, G. M., & Scheett, T. P. (2013). Sodium bicarbonate supplementation improves hypertrophy-type resistance exercise performance. *European Journal of Applied Physiology*, *113*(3), 743–752. https://doi.org/10.1007/S00421-012-2484-8

Coombes, J., & McNaughton, L. R. (1993). Effects of Bicarbonate Ingestion on Leg Strength and Power During Isokinetic Knee Flexion and Extension. *Journal of Strength and Conditioning Research*, *7*(4), 241–249. https://doi.org/10.1519/00124278-199311000-00009

Dalle, S., Koppo, K., & Hespel, P. (2021). Sodium bicarbonate improves sprint performance in endurance cycling. *Journal of Science and Medicine in Sport*, *24*(3), 301–306. https://doi.org/10.1016/j.jsams.2020.09.011

Ding, H., Hu, G. L., Zheng, X. Y., Chen, Q., Threapleton, D. E., & Zhou, Z. H. (2015). The method quality of cross-over studies involved in Cochrane Systematic Reviews. *PLoS ONE*, *10*(4). https://doi.org/10.1371/JOURNAL.PONE.0120519

Duncan, M. J., Weldon, A., & Price, M. J. (2014). The effect of sodium bicarbonate ingestion on back squat and bench press exercise to failure. *Journal of Strength and Conditioning Research*, *28*(5), 1358–1366. https://doi.org/10.1519/JSC.0000000000000277

Eriksen, M. B., & Frandsen, T. F. (2018). The impact of patient, intervention, comparison, outcome (PICO) as a search strategy tool on literature search quality: a systematic review. *Journal of the Medical Library Association : JMLA*, *106*(4), 420–431. https://doi.org/10.5195/JMLA.2018.345

Fitts, R. H. (2016). The Role of Acidosis in Fatigue. *Medicine & Science in Sports & Exercise*, *48*(11), 2335–2338. https://doi.org/10.1249/MSS.0000000000001043

Fontanella, L. R., Azara, C., Scudese, E., de Oliveira Silva, D., Nogueira, C. J., Costa, M. S. E., & Senna, G. W. (2020). Sodium bicarbonate supplementation in resistance exercise performance, perceived exertion and blood lactate concentration. *Motriz. Revista de Educacao Fisica*, *26*(1). https://doi.org/10.1590/S1980-6574202000010215

Froio de Araujo Dias, G., da Eira Silva, V., de Salles Painelli, V., Sale, C., Giannini Artioli, G., Gualano, B., & Saunders, B. (2015). (In)Consistencies in Responses to Sodium Bicarbonate Supplementation: A Randomised, Repeated Measures, Counterbalanced and Double-Blind Study. *PLOS ONE*, *10*(11), e0143086.

https://doi.org/10.1371/journal.pone.0143086

Ghroubi, S., Kossemtini, W., Mahersi, S., Elleuch, W., Chaabene, M., & Elleuch, M. H. (2016). Contribution of isokinetic muscle strengthening in the rehabilitation of obese subjects. *Annals of Physical and Rehabilitation Medicine*, *59*(2), 87–93. https://doi.org/10.1016/J.REHAB.2016.01.005

Grgic, J., Garofolini, A., Pickering, C., Duncan, M. J., Tinsley, G. M., & Del Coso, J. (2020). Isolated effects of caffeine and sodium bicarbonate ingestion on performance in the Yo-Yo test: A systematic review and meta-analysis. *Journal of Science and Medicine in Sport*, *23*(1), 41–47. https://doi.org/10.1016/j.jsams.2019.08.016

Grgic, J., Pedisic, Z., Saunders, B., Artioli, G. G., Schoenfeld, B. J., McKenna, M. J., Bishop, D. J., Kreider, R. B., Stout, J. R., Kalman, D. S., Arent, S. M., VanDusseldorp, T. A., Lopez, H. L., Ziegenfuss, T. N., Burke, L. M., Antonio, J., & Campbell, B. I. (2021). International Society of Sports Nutrition position stand: sodium bicarbonate and exercise performance. *Journal of the International Society of Sports Nutrition*, *18*(1), 61. https://doi.org/10.1186/s12970-021-00458-w

Grgic, J., Rodriguez, R. F., Garofolini, A., Saunders, B., Bishop, D. J., Schoenfeld, B. J., & Pedisic, Z. (2020). Effects of Sodium Bicarbonate Supplementation on Muscular Strength and Endurance: A Systematic Review and Meta-analysis. *Sports Medicine*, *50*(7), 1361–1375. https://doi.org/10.1007/s40279-020-01275-y

Gurton, W. H., Gough, L. A., Sparks, S. A., Faghy, M. A., & Reed, K. E. (2020). Sodium Bicarbonate Ingestion Improves Time-to-Exhaustion Cycling Performance and Alters Estimated Energy System Contribution: A Dose-Response Investigation. *Frontiers in Nutrition*, *7*. https://doi.org/10.3389/fnut.2020.00154

Hadzic, M., Eckstein, M. L., & Schugardt, M. (2019). The Impact of Sodium Bicarbonate on Performance in Response to Exercise Duration in Athletes: A Systematic Review. *Journal of Sports Science & Medicine*, *18*(2), 271-281. /pmc/articles/PMC6544001/

Heibel, A. B., Perim, P. H. L., Oliveira, L. F., McNaughton, L. R., & Saunders, B. (2018). Time to Optimize Supplementation: Modifying Factors Influencing the Individual Responses to Extracellular Buffering Agents. *Frontiers in Nutrition*, *5*. https://doi.org/10.3389/fnut.2018.00035

Hilton, N. P., Leach, N. K., Sparks, S. A., Gough, L. A., Craig, M. M., Deb, S. K., & McNaughton, L. R. (2019). A Novel Ingestion Strategy for Sodium Bicarbonate Supplementation in a Delayed-Release Form: a Randomised Crossover Study in Trained Males. *Sports Medicine - Open*, *5*(1), 4. https://doi.org/10.1186/s40798-019-0177-0

Horwath, O., Paulsen, G., Esping, T., Seynnes, O., & Olsson, M. C. (2019). Isokinetic resistance training combined with eccentric overload improves athletic performance and induces muscle hypertrophy in young ice hockey players. *Journal of Science and Medicine in Sport*, *22*(7), 821–826. https://doi.org/10.1016/J.JSAMS.2018.12.017

Klemp, A., Dolan, C., Quiles, J. M., Blanco, R., Zoeller, R. F., Graves, B. S., & Zourdos, M. C. (2016). Volume-equated high- and low-repetition daily undulating programming strategies produce similar hypertrophy and strength adaptations.

Applied Physiology, Nutrition, and Metabolism = Physiologie Appliquee, Nutrition et Metabolisme, *41*(7), 699–705. https://doi.org/10.1139/APNM-2015-0707

Krzysztofik, M., Wilk, M., Wojdała, G., & Gołaś, A. (2019). Maximizing Muscle Hypertrophy: A Systematic Review of Advanced Resistance Training Techniques and Methods. *International Journal of Environmental Research and Public Health*, *16*(24), 4897. https://doi.org/10.3390/IJERPH16244897

Kubo, K., Ikebukuro, T., & Yata, H. (2021). Effects of 4, 8, and 12 Repetition Maximum Resistance Training Protocols on Muscle Volume and Strength. *Journal of Strength and Conditioning Research*, *35*(4), 879–885. https://doi.org/10.1519/JSC.0000000000003575

La Scala Teixeira, C. V., Evangelista, A. L., Pereira, P. E. de A., Da Silva-Grigoletto, M. E., Bocalini, D. S., & Behm, D. G. (2019). Complexity: A Novel Load Progression Strategy in Strength Training. *Frontiers in Physiology*, *10*, 839. https://doi.org/10.3389/FPHYS.2019.00839/BIBTEX

Lancha Junior, A. H., de Salles Painelli, V., Saunders, B., & Artioli, G. G. (2015). Nutritional Strategies to Modulate Intracellular and Extracellular Buffering Capacity During High-Intensity Exercise. *Sports Medicine*, *45*(S1), 71–81. https://doi.org/10.1007/s40279-015-0397-5

Lima, F. G. de, Fidale, T. M., Silva, G. D. F., Faria, M. M. de, Resende, E. S., Rocha Júnior, L. D. D. U., & Costa Junior, M. (2020). Acute effect of sodium bicarbonate supplementation by resistant training practices. *Bioscience Journal* , *36*(4), 1429–1437. https://doi.org/10.14393/BJ-V36N4A2020-48176

Lindh, A., Peyrebrune, M., Ingham, S., Bailey, D., & Folland, J. (2008). Sodium Bicarbonate Improves Swimming Performance. *International Journal of Sports Medicine*, *29*(6), 519–523. https://doi.org/10.1055/s-2007-989228

Lopes-Silva, J. P., Reale, R., & Franchini, E. (2019). Acute and chronic effect of sodium bicarbonate ingestion on Wingate test performance: a systematic review and meta-analysis. *Journal of Sports Sciences*, *37*(7), 762–771. https://doi.org/10.1080/02640414.2018.1524739

Materko, W., Neves, C. E. B., & Santos, E. L. (2008). Effect of Bicarbonate Supplementation on the Muscular Strength. *Medicine & Science in Sports & Exercise*, *11(6)*, 25-33. https://doi.org/10.1249/00005768-200605001-02596

Matson, L. G., & Tran, Z. V. (1993). Effects of sodium bicarbonate ingestion on anaerobic performance: a meta-analytic review. *International Journal of Sport Nutrition*, *3*(1), 2–28. https://doi.org/10.1123/IJSN.3.1.2

Matta, T. T., Nascimento, F. X., Trajano, G. S., Simão, R., Willardson, J. M., & Oliveira, L. F. (2017). Selective hypertrophy of the quadriceps musculature after 14 weeks of isokinetic and conventional resistance training. *Clinical Physiology and Functional Imaging*, *37*(2), 137–142. https://doi.org/10.1111/CPF.12277

Maughan, R. J., Burke, L. M., Dvorak, J., Larson-Meyer, D. E., Peeling, P., Phillips, S. M., Rawson, E. S., Walsh, N. P., Garthe, I., Geyer, H., Meeusen, R., Van Loon, L., Shirreffs, S. M., Spriet, L. L., Stuart, M., Vernec, A., Currell, K., Ali, V. M., Budgett, R. G. M., … Engebretsen, L. (2018). IOC Consensus Statement: Dietary Supplements and the High-Performance Athlete. *International Journal of Sport*

Nutrition and Exercise Metabolism, *28*(2), 104–125. https://doi.org/10.1123/IJSNEM.2018-0020

Moriones, V. S., & Santos, J. I. (2017). [Ergogenic aids in sport]. *Nutricion Hospitalaria*, *34*(1), 204–215. https://doi.org/10.20960/NH.997

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ (Clinical Research Ed.)*, *372*, *n71*. https://doi.org/10.1136/BMJ.N71

Portington, K. J., Pascoe, D. D., Webster, M. J., Anderson, L. H., Rutland, R. R., & Gladden, L. B. (1998). Effect of induced alkalosis on exhaustive leg press performance. *Medicine &amp Science in Sports &amp Exercise*, *30*(4), 523–528. https://doi.org/10.1097/00005768-199804000-00009

Robergs, Robert A., Ghiasvand, F., & Parker, D. (2004). Biochemistry of exercise-induced metabolic acidosis. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *287*(3), R502–R516. https://doi.org/10.1152/ajpregu.00114.2004

Robergs, Robert Andrew. (2017). Competitive cation binding computations of proton balance for reactions of the phosphagen and glycolytic energy systems within skeletal muscle. *PloS One*, *12*(12). https://doi.org/10.1371/JOURNAL.PONE.0189822

Sahlin, K. (1992). Metabolic Factors in Fatigue. *Sports Medicine*, *13*(2), 99–107. https://doi.org/10.2165/00007256-199213020-00005

Sartori, R., Romanello, V., & Sandri, M. (2021). Mechanisms of muscle atrophy and hypertrophy: implications in health and disease. *Nature Communications*, *12*(1), 330. https://doi.org/10.1038/S41467-020-20123-1

Saunders, B., Sale, C., Harris, R. C., & Sunderland, C. (2014). Sodium Bicarbonate and High-Intensity-Cycling Capacity: Variability in Responses. *International Journal of Sports Physiology and Performance*, *9*(4), 627–632. https://doi.org/10.1123/ijspp.2013-0295

Schoenfeld, B., & Grgic, J. (2018). Evidence-based guidelines for resistance training volume to maximize muscle hypertrophy. *Strength and Conditioning Journal*, *40*(4), 107–112. https://doi.org/10.1519/SSC.0000000000000363

Schoenfeld, B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. *Journal of Strength and Conditioning Research*, *24*(10), 2857–2872. https://doi.org/10.1519/JSC.0B013E3181E840F3

Schoenfeld, B. J., Ogborn, D. I., & Krieger, J. W. (2015). Effect of Repetition Duration During Resistance Training on Muscle Hypertrophy: A Systematic Review and Meta-Analysis. *Sports Medicine*, *45*(4), 577–585. https://doi.org/10.1007/S40279-015-0304-0/FIGURES/3

Schoenfeld, B. J., Ratamess, N. A., Peterson, M. D., Contreras, B., Sonmez, G. T., & Alvar, B. A. (2014). Effects of different volume-equated resistance training loading strategies on muscular adaptations in well-trained men. *Journal of Strength and Conditioning Research*, *28*(10), 2909–2918. https://doi.org/10.1519/JSC.0000000000000480

Siegler, J. C., & Hirscher, K. (2010). Sodium Bicarbonate Ingestion and Boxing Performance. *Journal of Strength and Conditioning Research*, *24*(1), 103–108. https://doi.org/10.1519/JSC.0b013e3181a392b2

Siegler, J. C., Marshall, P. W. M., Finn, H., Cross, R., & Mudie, K. (2018). Acute attenuation of fatigue after sodium bicarbonate supplementation does not manifest into greater training adaptations after 10-weeks of resistance training exercise. *PloS One*, *13*(5). https://doi.org/10.1371/JOURNAL.PONE.0196677

Taber, C. B., Vigotsky, A., Nuckols, G., & Haun, C. T. (2019). Exercise-Induced Myofibrillar Hypertrophy is a Contributory Cause of Gains in Muscle Strength. *Sports Medicine, 49*(7), 993–997. https://doi.org/10.1007/S40279-019-01107-8

Webster, M. J., Webster, M. N., Crawford, R. E., & Bruce Gladden, L. (1993). Effect of sodium bicarbonate ingestion on exhaustive resistance exercise performance. *Medicine and Science in Sports and Exercise*, *25*(8), 960–965. https://doi.org/10.1249/00005768-199308000-00012

7. Tables and Figures

Table 1. Summary of the included studies that explored the effects of sodium bicarbonate supplementation on hypertrophy-type resistance exercise performance.

Study (year)	Population characteristics	Performance assessment	NaHCO3 Intervention	Changes in pH and blood lactate	Side effects	Effects on hypertrophy exercise performance
Balberman (1983)	10 male college students	Isokinetic knee flexion and extension work for one-legged, total work and number of contractions	0.3 g/kg-1 of $NaHCO_3$; 180 min pre-exercise	[pH: Placebo: basal (7.44 ±0,01); pre-exercise (7.45 ±0,02); post-exercise (7,34 ±0,04) / $NaHCO_3$: basal (7.44 ±0,02); pre-exercise (7.45±0,02); post-exercise (7,42 ±0,04)]	Diarrhea in some participants	An increased total work ($NaHCO_3$: 733 Kj ± 142, NH4CI: 723 Kj ± 136, control: 728 Kj ± 150; $p > 0.05$).
Caar et al. (2013)	12 resistance-trained men	4 sets of squat, leg press and leg extension to muscle failure; total repetitions and 1 additional set of knee extension to failure (50%RM)	0.3 g/kg-1 of $NaHCO_3$; 60 min pre-exercise	[pH: Placebo: basal (7.42 ±0,02); pre-exercise (7.42 ±0,02); post-exercise (7,28 ±0,04) / NaHCO3: basal (7.43 ±0,02); pre-exercise (7.49±0,02); post-exercise (7,35±0,04)] [Lactate: Placebo: pre-exercise (1.68 mM ±0,46); post-exercise (15,55 mM ±2,50) / $NaHCO_3$: pre-exercise (1.83 mM ±0,33); post-exercise (17,92 mM ±2,08)]	Light-headedness and eructation in 1 participant	More total repetitions ($NaHCO_3$: 139.8 reps ± 13.2, placebo: 134.4 reps ± 13.5; $p < 0.05$)
Coombes & McNaughton (1993)	9 healthy male physical	Isokinetic leg flexion and extension;	0.3 g/kg-1 of $NaHCO_3$;	[pH: Placebo: basal (7.33 ±0,04); pre-exercise (7.33 ±0,03); post-exercise (7,20 ±0,06) / $NaHCO_3$: basal (7.33	None	More isokinetic work ($NaHCO_3$: 10.756 Kj ±

	education students	peak torque and total work (flexion-extension)	90 min pre-exercise	±0,03); pre-exercise (7.39±0,04); post-exercise (7,17 ±0,06)]		1.441, placebo: 10.096 Kj ± 1.393; p <0.05)
Duncan et al. (2014)	8 resistance-trained men	3 sets to failure (80%RM) in back squat and bench press; total repetitions	0.3 g/kg-1 of $NaHCO_3$; 60 min pre-exercise	[pH: Placebo: basal (7.4 ±0,01); pre-exercise (7.4 ±0,03); post-squad (7,3 ±0,03) / $NaHCO_3$: basal (7.4 ±0,01); pre-exercise (7.4±0,01); post-squad (7,4±0,05)] [Lactate: Placebo: pre-exercise (1.6 mM ±0,6); post-squad (10,3 mM ±5,1) / NaHCO3: pre-exercise (1.7 mM ±1,1); post-squad (11,9 mM ±4,2)]	Gastrointestinal distress in 3 participants	More repetitions in the back squat ($NaHCO_3$: 31.3 reps ± 15.3, placebo: 24.6 reps ± 16.2; p = 0.04) , but not for bench press ($NaHCO_3$: 28.7 reps ± 12.2, placebo: 26.7 reps ± 10.2; p = 0.679)
Fontanella et al. (2020)	14 resistance-trained men	Resistance exercise session: 5 sets (15RM) in bech press, machine chest fly and triceps pushdown; number of repetitions in each set and total number of repetitions	0.3 g/kg-1 of $NaHCO_3$; 30 min pre-exercise	Not assessed	None	Greater total repetitions in machine chest fly (p = 0.04), but no more repetitions for the overall exercise session ($NaHCO_3$: 92.43 reps ± 10.43; placebo: 91.71 reps ± 8.91; p = 0.847)

Lima et al. (2020)	10 resistance-trained adult men	8 sets until failure (80%RM) in the extensor chair (4 sets) and direct thread (4 sets); total maximal number of reps	0.3 g/kg-1 of $NaHCO_3$; 30 min pre-exercise	[Lactate: Placebo: pre-exercise (3.72 mM ±1,66); post-exercise (8,60 mM ±2,75) / $NaHCO_3$: pre-exercise (4,07 mM±2,41); post-exercise (9,18 mM ±4,50)]	Gastrointestinal discomfort in some participants	More number of repetitions ($NaHCO_3$: 67.70 reps ±15.59, placebo: 64.60 reps ±10.61; p= 0.61)
Materko et al. (2008)	11 resistance-trained male	1 maximal set on the bench press and on the pull press	0.3 g/kg-1 of $NaHCO_3$; 120 min pre-exercise	Not assessed	Not reported	No ergogenic effects
Portington et al. (1998)	15 resistance-trained male	5 maximal sets on leg press machine; total repetitions	0.3 g/kg-1 of $NaHCO_3$; 120 min pre-exercise	[pH: Placebo: basal (7.40); pre-exercise (7.40); post-exercise (7,26) / $NaHCO_3$: basal (7.40); pre-exercise (7.47); post-exercise (7,33)] [Lactate: Placebo: pre-exercise (4.6 mM); post-exercise (11,3 mM) / $NaHCO_3$: pre-exercise (4.8 mM); post-exercise (13.4 mM)]	Gastrointestinal distress in 4 participants	No difference in total repetitions ($NaHCO_3$ = 59 reps ± 3; placebo = 60 reps ± 2)
Siegler et al. (2018)	8 resistance trained, 6 men and 2 women	5 sets of leg extension to muscle failure; number of repetitions and torque development	0.3 g/kg-1 of $NaHCO_3$; 90 to 30 min pre-exercise	[pH: Placebo: pre-exercise (7,42±0,02)/ $NaHCO_3$: pre-exercise (7,46±0,02)]	None reported	No difference in the number of repetitions

Webster (1993)	6 resistance-trained male	4 sets of 12 repetitions with a 5 set to failure on leg press machine (70%RM); number of repetitions on the 5th set	0.3 g/kg-1 of $NaHCO_3$; 105 min pre-exercise	[pH: Placebo: basal (7.40 ±0,02); pre-exercise (7.39 ±0,02); post-exercise (7,25) / $NaHCO_3$: basal (7.39 ±0,02); pre-exercise (7.46±0,02); post-exercise (7,32)] [Lactate: Placebo: pre-exercise (1.31 mM); post-exercise (9,81 mM) / $NaHCO_3$: pre-exercise (1.37 mM); post-exercise (11,15 mM)]	Upset stomach in one participant 2-3 hours after exercise	More number of repetitions ($NaHCO_3$: 19.6 reps ±1.6; placebo: 18.2 reps ±1.1; p= 0.29)

RM repetition maximum, NaHCO3 sodium bicarbonate, Reps repetitions.

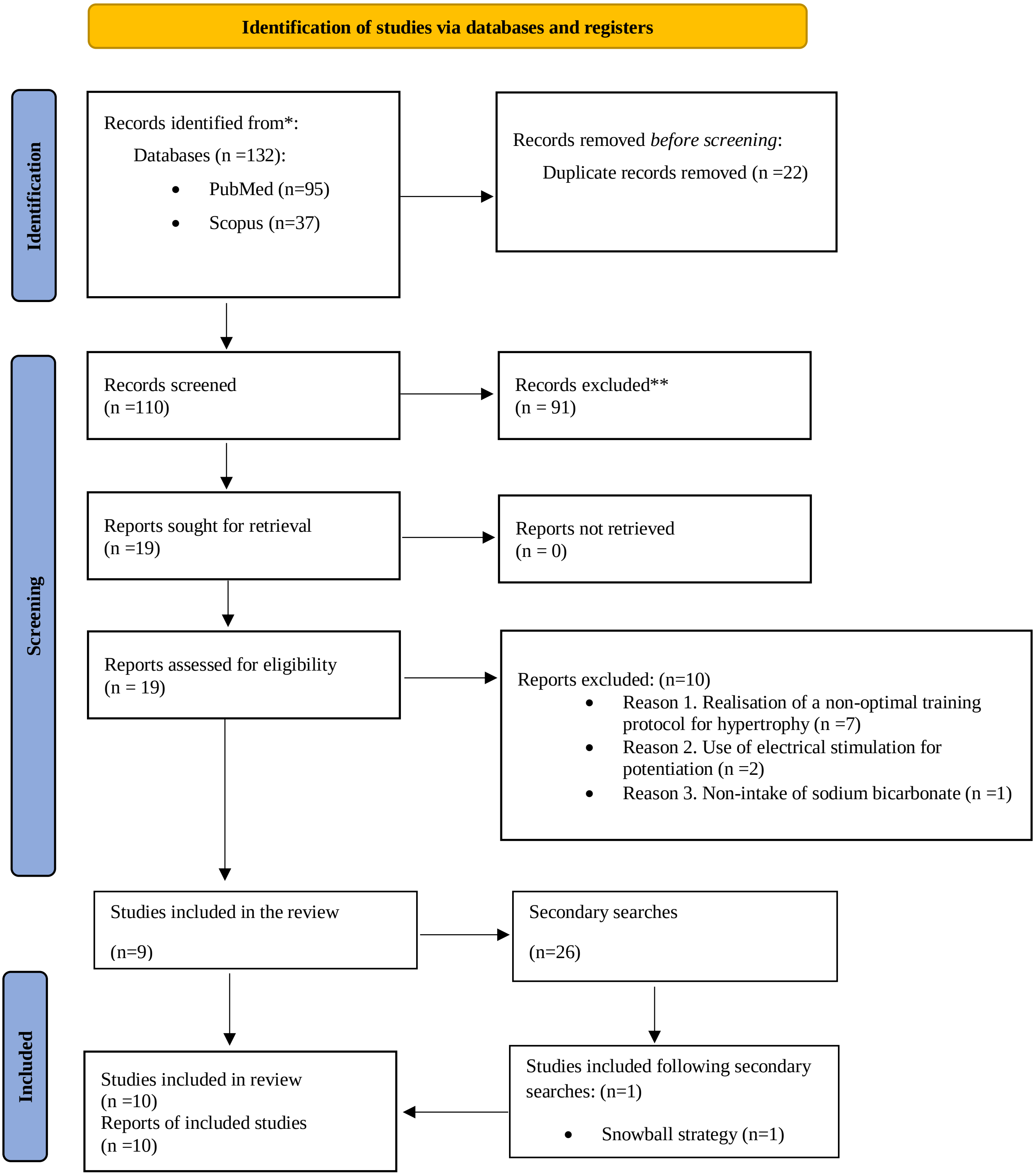

Figure 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only.

Table 2. Results of the methodological quality assessment using the using the Quality assessment standard for a cross-over study scale.

Studies	**Item 1: Appropriate cross-over design**	**Item 2: Randomized order of receiving treatment**	**Item 3: Carry-over effects**	**Item 4: Unbiased data**	**Item 5: Allocation concealment**	**Item 6: Blinding**	**Item 7: Incomplete outcome data**	**Item 8: Selective outcome reporting**	**Item 9:Other bias**
Balberman (1983)	Low	Low	Unclear	Low	Unclear	Low	Low	Low	Low
Caar et al. (2013)	Low	Low	Unclear	Low	Unclear	Low	Low	Low	Low
Coombes & McNaughton (1993)	Low	Low	Unclear	Low	Unclear	Low	Low	Low	Low
Duncan et al. (2014)	Low	Low	Unclear	Low	Unclear	Low	Low	Low	Low
Fontanella et al. (2020)	Low	Low	Unclear	Low	Unclear	Unclear	Low	Low	Low
Lima et al. (2020)	Low	Low	Unclear	Low	Unclear	Low	Low	Low	Low
Materko et al. (2008)	Unclear	Low	Unclear	Low	Unclear	Low	Low	Low	Low
Portington et al. (1998)	Low	Low	Unclear	Low	Unclear	Low	Low	Low	Low
Siegler et al. (2018)	Low	Low	Unclear	Low	Unclear	Low	Low	Low	Low
Webster (1993)	Low	Low	Unclear	Low	Unclear	Low	Low	Low	Low