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Review article

The Impact of Sodium Bicarbonate on Performance in Response to Exercise Duration in Athletes: A Systematic Review

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Abstract
According to recent literature sodium bicarbonate ($NaHCO_3$) has been proposed as a performance enhancing aid by reducing acidosis during exercise. The aim of the current review is to investigate if the duration of exercise is an essential factor for the effect of $NaHCO_3$. To collect the latest studies from electronic database of PubMed, study publication time was restricted from December 2006 to December 2016. The search was updated in July 2018. The studies were divided into exercise durations of > 4 or ≤ 4 minutes for easier comparability of their effects in different exercises. Only randomized controlled trials were included in this review. Of the 775 studies, 35 met the inclusion criteria. Study design, subjects, effects as well as outcome criteria were inconsistent throughout the studies. Seventeen of these studies reported performance enhancing effects after supplementing $NaHCO_3$. Eleven of twenty studies with exercise duration of ≤ 4 minutes showed positive and four diverse results after supplementing $NaHCO_3$. On the other hand six of fifteen studies with an exercise duration of >4 minutes showed performance enhancing and two studies showed diverse results. Consequently, the duration of exercise might be influential for inducing a performance enhancing effect when supplementing $NaHCO_3$, but to which extent, remains unclear due to the inconsistencies in the study results.

Key words: Sodium bicarbonate; supplementation; acute; chronic; performance outcome.

Introduction

Blood Bicarbonate (HCO_3-) is part of the acid base homeostatic bicarbonate buffer system, which is critical in regulating blood pH concentrations and supporting metabolic functions. If blood pH is too alkaline a proton (H+) dissolves from carbonic acid ($H2CO_3$) forming HCO3-. On the contrary, HCO_3- binds a proton if blood pH is too acidic, resulting in H2CO3 again dissociating into water (H_2O) and carbon dioxide (CO_2). This leads to increased breathing rate in an attempt to exhale CO_2 and restore acid-base balance. The additional buffering capacity of exogenous HCO3- led to increased blood lactate after exercise, which is suspected to be due to greater efflux of H+ (Close et al., 2016; Peart et al., 2012; Felippe et al., 2016; Talbott et al., 1931). Also, adding sodium bicarbonate ($NaHCO_3$) appears to influence phosphocreatine degradation (PCr) and inorganic phosphate (Pi) accumulation [(PCr/ (Pi)], glycolytic intermediates (muscle protons and lactate), intra- and extracellular distribution of metabolites and other strong ions (Na+, K + and Cl) which appear to contribute to a performance enhancing effect (Siegler et al., 2016).

Consequently, in recent years $NaHCO_3$ has attracted a lot of attention as it was shown to significantly improve performance by up to 3% in swimming and cycling athletes (Carr et al., 2011a; Mueller et al., 2013; Mero et al., 2013). Yet, studies have shown that $NaHCO_3$ may not only be an ergogenic, but also an ergolytic substance (Deb et al., 2018). The reasoning behind this may lie within the mechanism of action, as the bicarbonate buffer system is not solely responsible for blood pH but is also vital in other systems, such as the stomach and duodenum by neutralizing gastric acid. As a sensitive contributor to those multifactorial processes, a potential limitation of performance is possible. Participants supplementing $NaHCO_3$ reported gastrointestinal (GI) upset including nausea, stomach pain, diarrhea and vomiting (Saunders et al., 2014; Carr et al., 2011b). On the one hand, dosage is suspected to have a large effect on ergogenic potential and GI distress, whereas 0.2 up to 0.4 g/kg body mass has prevailed as being tolerable (Burke, 2013; Lindh et al., 2008). On the other hand, the effects of type (fluid solution or capsule) and time of consumption are also unclear as results of acute (0.5 – 4 h prior exercise) or chronic loading of $NaHCO_3$ (several days prior exercise) led to diverse results (Joyce et al., 2012; Zajac et al., 2009).

Also, a large proportion of empirical research and systematic reviews have approached the complex topic of alkalizing ergogenic aids, especially $NaHCO_3$ (Close et al., 2016; Siegler et al., 2016; Burke, 2013). Yet, during exercise trials neither administering $NaHCO_3$ via fluid solutions, tablets or gelatin capsules, nor combining it with creatine (CR), beta-alanine (BA) or caffeine (CAF) led to the desired incontestable results (Pruscino et al., 2008; Kilding et al., 2012; Barber et al., 2013; Painelli et al., 2013). On that account, it can be suspected that there are more factors influencing the effect of $NaHCO_3$ supplementation such as training condition, athletes' class (college, elite. Olympic etc.), gender or duration of exercise. A recent review summarized that $NaHCO_3$ is effective in trained athletes across a range of exercises such as supramaximal exercise, high intensity intermittent activity as well as skill-based sports (McNaughton et al., 2016). This review included also randomized controlled trials (RCT) which have tested $NaHCO_3$ via numerous diverse exercise tasks (e.g. bench press, judo throw test, upper body Wingate test, rugby

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sprint test) which lasted between 60 seconds up to 60 minutes (McNaughton et al., 2016).

In opposition to the aforementioned literature review, we would like to approach this topic differently by focusing less on the type of exercise tasks, but more on the exercise duration which we believe might be a major contributor to the effect on the performance of $NaHCO_3$. This has previously been a subject of investigation in a study by McNaughton in 1992 investigating the effect of anaerobic exercise over various durations (McNaughton, 1992). However, a major issue occurs when exercise trials are analyzed and interpreted regarding their metabolic impact (e.g. increase in lactate), because most trials conduct multiple exercise bouts and either investigate them individually or in sum. A good example for this is the 4x4 method which uses 4 min bouts of exercise corresponding to 90-95% of the maximum heart rate (HRmax) interspersed with 3 min of active recovery at 70% HRmax (Helgerud et al., 2007; Wisløff et al., 2007). This protocol is considered aerobic, yet other studies were unable to reproduce a lactate steady state (LaSS) when this protocol was applied (Tschakert et al., 2015; Hofmann and Tschakert, 2010). Since we did not assume that all studies included in this review would determine metabolic responses to exercise (e.g. lactate levels) we have decided to set the exercise duration cut-off at $\leq$ 4 minutes when prescribed exercise intensity was considered 'High' (Table 1). The reason behind this was to ensure that the previously shown mitigating effects of $NaHCO_3$ on metabolic acidosis (i.e. decline in pH) induced by predominantly anaerobic high-intensity exercise represents a potentially performance enhancing effect (Gough et al., 2017).

As such, the aim of this review is to assist in the quantification of how $NaHCO_3$ acts during 'short' and predominantly anaerobic exercise tasks providing practitioners, coaches and athletes a valid tool for implementing this supplement in their methods. Since various exercise tests were analyzed in this review, active and passive resting periods were also taken into account.

Methods

A systematic search of literature was conducted in the electronic database of PubMed. To examine the latest studies, the study publication time was restricted from December 2006 to December 2016. Due to additional valuable publications in this field, the search was updated in July 2018. Only RCT's were included. The search terms used were "sodium bicarbonate" according to MeSH (Medical Subject Headings) AND "athlete AND performance OR exercise OR recovery". Two authors (MLE; MH) performed the literature search independently; disagreements were discussed and solved with total consistency. The search process included screening titles, abstracts and eligible full texts. In addition, reference lists of excluded systematic reviews, reviews and included and excluded articles were manually screened for studies of relevance. A flowchart for screening and selection of studies is shown in Figure 1.

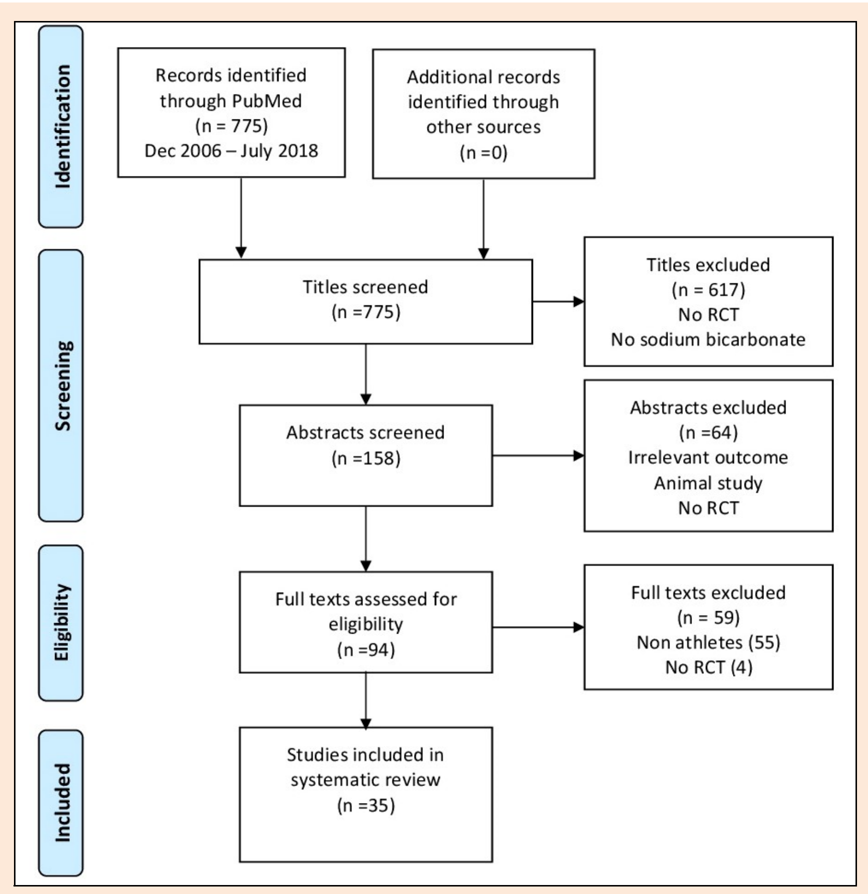

Figure 1. Flowchart for screening and selection of studies according to PRISMA. Dec: December.

Eligibility criteria

The inclusion criteria of the present study consisted of: (a) field or laboratory RCT's that were either single- or double-blinded; (b) trials that included participants that were referred to as athletes or fulfilled the definition made by Araújo & Scharhag (Araújo and Scharhag, 2016); (c) all possible sports respecting both genders; (d) placebo-controlled designs involving $NaHCO_3$ or any combination of $NaHCO_3$ with other substances like beta alanine (BA), caffeine (CAF) or creatine (CR); (e) exercise/performance as a main outcome. We excluded studies that investigated sodium citrate or sodium pyruvate as a main outcome, did not investigate exercise related performance parameters or did not give a detailed explanation about participation in competitions or comparable training status of the participants.

Data extraction

Data extracted from each eligible full text were: the first author's last name, publication year, study design, country, study duration, performance level and type of sport, subject information (sample size, sex, age and weight), supplementation (type, dose, time of ingestion), exercise performed (name, type, frequency) and outcome parameters including exercise duration. Overall, the results of the included studies are presented in different units or parameters. Therefore, to determine the effectiveness of $NaHCO_3$ we summarized the effect as "Yes", "No" or "Yes/No", based on the study results and significance values ($p < 0.05$).

Risk of bias assessment

The Cochrane Collaborations' risk of bias assessment tool was used to evaluate the internal validity of the included RCTs (Higgins et al., 2011). Each included study was examined independently by the two authors (MLE, MH) by the defined sources of bias, which are: selection bias (sequence generation and allocation concealment), performance bias (blinding of participants and personnel), detection bias (blinding of outcome assessors), attrition bias (incomplete outcome data), selective reporting bias and other potential bias. Discrepancies were resolved by consensus.

Results

Initial search was performed in December 2016 and updated in July 2018. In the end 775 studies could be identified. After screening titles, a total of 617 were excluded, because they did not include $NaHCO_3$ or were not a RCT. When screening abstracts, further 64 studies were excluded because of irrelevant outcome, animal study or no RCT. The assessment of the remaining 94 full text articles led to the exclusion of further 59 studies because of non-athletic population or no RCT. Consequently 35 articles were available for final evaluation.

Study characteristics

Detailed information about study characteristics, results as well as task duration and supplementation can be found in Table 1, 2 and 3. The average sample size across all included studies was 15 athletes (range = 6-49; NTotal = 507). Overall athlete's age ranged from 15 to 34 years.

The majority of studies used 0.3 g/kg body mass (BM) of $NaHCO_3$, whereas only three studies used 0.4 g/kg BM, three studies used 0.125 g/kg BM or less and one study used 0.5 g/kg BM. Delivery of $NaHCO_3$ was conducted differently throughout the studies. Most of the studies [n=21] used gelatin capsules for supplementation, whereby 12 studies supplemented with fluid solutions. Two studies used tablets.

Exercise tasks included in this review were rowing [n=5] (Christensen et al., 2014; Hobson et al., 2014; Hobson et al., 2013; Kupcis et al., 2012; Driller et al., 2013) ,sport specific trials [n=8] e.g. rugby sprint (Cameron et al., 2010), water polo (Tan et al., 2010), boxing (Siegler and Hirscher, 2010), basketball (Afman et al., 2014), judo (Felippe et al., 2016), taekwondo (Lopes-Silva et al., 2018), wrestling (Durkalec-Michalski et al., 2018), tennis (Wu et al., 2010), cycling tasks [n=6] (Mueller et al., 2013; Kilding et al., 2012; Egger et al., 2014; Thomas et al., 2016; Zabala et al., 2011; Zabala et al., 2008), swimming [n=7] (Mero et al., 2013; Lindh et al., 2008; Joyce et al., 2012; Zajac et al., 2009; Pruscino et al., 2008; Painelli et al., 2013; Siegler and Gleadall-Siddall, 2010), running [n=6] (Krustrup et al., 2015; Marriott et al., 2015; Stöggl et al., 2014; Ducker et al., 2013; McClung and Collins, 2007; Freis et al., 2017), upper body tasks (Tobias et al., 2013; Oliveira et al., 2017) and resistance training (Duncan et al., 2014). Regarding the duration of exercise, 14 trials lasted over four minutes and 17 trials lasted four or less than four minutes using acute supplementation, which means the supplement was taken in one to five equal doses, whereby the first dose was taken either 150, 120, 90, 75 or 60 minutes before exercise. These doses had to be consumed throughout 60 or 30 minutes, every 10 or every 15 minutes depending on the study design (Table 1 and 2).

Chronic supplementation was seen in one study including an exercise longer than four minutes and four studies with a trial duration equal to or less than four minutes. The duration of the chronic supplementation varied across the studies. The only study with a trial duration over four minutes ingested the supplement on two days per week over a period of eight weeks (Driller et al., 2013). One study with exercise duration below four minutes ingested the supplement three times per day over a period of three days (Joyce et al., 2012), while the other two studies expanded this protocol to four times a day over five (Oliveira et al., 2017) and seven (Tobias et al., 2013) days, respectively. The most recent study used a progressive protocol over 10 days starting with 0.025 g/kg BM on days one and two and increasing the dose until the last day to 0.1 g/kg BM to ensure no GI stress (Durkalec-Michalski et al., 2018). One of the 35 studies included in this review investigated acute and chronic supplementation at the same time and is therefore treated as two separate studies in further procedure (Joyce et al., 2012) (Table 1; Table 3).

Table 1. Acute $NaHCO_3$ supplementation, exercise duration ≤ 4 minutes.

Article	Athletes	Supplementation (type/dose)	Ingestion (min before exercise)	Exercise	Exercise Time	Intensity	Side Effects	Effects of $NaHCO_3$	
de Salles Painelli et al. 2013	Competitive swimmers	Capsule; 0.3 g/kg BM	90	100 / 200 m swim	< 70 s / < 120 s	High	Mild	YES/NO	Combined with BA, $NaHCO_3$ improved 200 m time (F=1.36; p=0.28), but not 100 m (F=5.17; p=0.024).
Duncan et al. 2014	Experienced athletes	Fluid solution; 0.3 g/kg BM	60	80% 1RM barbell exercise	10 - 12 repetitions	High	Mild	YES/NO	$NaHCO_3$ improves back squat ($F_{(1,7)}$=10.98; p=0.04), but not bench press (p=0.428).
Felippe et al. 2016	Experienced judo athletes	Capsule; 0.3 g/kg BM	120, 90, 60	Special judo fitness test	3 x 1.15 min	High	None	YES/NO	Only $NaHCO_3$ does not improve performance, but combined with caffeine (F=0.80; p=0.02).
McClung et al. 2007	Endurance athletes	Fluid solution; 0.3 g/kg BM	120 - 90	5 x 1000 m run	5 x 3 min	High	Mild	YES	$NaHCO_3$ resulted in performance improvement and lowered blood lactate ($F_{(1,15)}$=51.4; p<0.001; η^2=0.774).
Lindh et al. 2008	Elite swimmers	Capsule; 0.3 g/kg BM	90 - 60	200 m swim	< 2 min	High	None	YES	$NaHCO_3$ improved performance in 8 out of 9 athletes by 1.6% (p=0.04).
Zajac et al. 2009	Well-trained swimmers	Fluid solution; 0.3 g/kg BM	90	4 x 50 m swim	4x < 30 s	High	None	YES	$NaHCO_3$ ingestion improves performance by 1.5 s compared to controls ($F_{(2,28)}$=5.63; p<0.05).
Siegler et al. 2010a	Competitive boxers	Fluid solution; 0.3 g/kg BM	60	Sparring bouts	4 x 3 min	High	Mild	YES	Punch efficacy increased after ingestion of $NaHCO_3$ (p>0.001).
Siegler et al. 2010b	University swimmers	Fluid solution; 0.3 g/kg BM	150	8 x 25 m swim	110 - 120 s	High	None	YES	$NaHCO_3$ improved total swim time by 2%. Mean difference overall was 4.4 seconds (d=0.15; p=0.04).
Kilding et al. 2012	Well-trained cyclists	Capsule; 0.3 g/kg BM	120, 90, 60	HIIT cycling	< 4 min	High	Mild	YES	Caffeine and $NaHCO_3$ consumed separately led to performance enhancements (ES= 0.21; p=0.01).
Ducker et al. 2013	Team sport players	Capsule; 0.3 g/kg BM	60	Repeated sprint test	~ 1 min	High	N/A	YES	Single $NaHCO_3$ supplementation improved performance (d=0.56).
Mero et al. 2013	Competitive swimmers	Capsule; 0.3 g/kg BM	60	2 x 100m swim	< 60 s	High	None	YES	$NaHCO_3$ improves swimming performance by 2.4% / 1.5s (p<0.05).
Thomas et al. 2016	Trained cyclists	Capsule; 0.3 g/kg BM	90	Cycling test	1.10 min	High	N/A	YES	Lesser VO_2 and VE decrease during trial while supplementing $NaHCO_3$ (r=0.74; p<0.01).
Pruscino et al. 2008	High elite swimmers	Capsule; 0.3 g/kg BM	120 - 30	2 x 200m swim	~ 2 min	High	N/A	NO	No significant improvement in time after ingestion of $NaHCO_3$ (ES=0.25±0.26; p=0.052).
Zabala et al. 2008	Professional BMX cyclists	Fluid solution; 0.3 g/kg BM	90	CMJ & Wingate cycling test	3 x 30 s	High	N/A	NO	No statistically significant effect on performance after ingesting $NaHCO_3$ (p>0.05).
Zabala et al. 2011	Elite national BMX cyclists	Capsule; 0.3 g/kg BM	90	CMJ & Wingate cycling test	3 x 30 s	High	None	NO	No improvements regarding performance after ingesting $NaHCO_3$ (p>0.05).
Joyce et al. 2012**	Competitive swimmers	Capsule; 0.3 g/kg BM	90	2 x 200 m swim	< 2 min	High	Mild	NO	Acute supplementation of $NaHCO_3$ had no effect on swimming performance (F=0.48; p=0.08).
Stöggl et al. 2014	Endurance athletes	Fluid solution; 0.3 g/kg BM	90, 10	Treadmill running bouts	3 x 2 min	High	Mild	NO	Improvements in lactate, blood pH and HCO_3^- was found while supplementing $NaHCO_3$ (p<0.01).

**paper is displayed twice as acute and chronic supplementation and was investigated separately. g: Gram; kg: Kilogram; BM: Body mass; min: Minutes; m: Meter; $NaHCO_3$: Sodium Bicarbonate; BA: Beta-alanine; 1RM: One-repetition maximum; HIIT: High-intensity interval training; BMX: Bicycle motocross; CMJ: Counter movement jump; N/A: Not applicable. High: Maximum effort; Mild: Minimum discomfort; None: No discomfort; VO_2: Oxygen consumption; VE: Ventilation; F: Fishers F test; d= Cohen's d; ES: Effect size; r= Pearson correlation

Table 2. **Acute $NaHCO_3$ supplementation, exercise duration > 4 minutes.**

Article	Athletes	Supplementation (type/dose)	Ingestion (min before exercise)	Exercise	Exercise Time	Intensity	Side Effects	Effects of $NaHCO_3$	
Christensen et al. 2014	Lightweight rowers	Capsule; 0.3 g/kg BM	75	Rowing test	6 min	High	None	YES/NO	Solely $NaHCO_3$ has no effect, but combined with caffeine (ES: 0.6; $p<0.01$).
Freis et al. 2017	Endurance athletes	Fluid Solution; 0.3 g/kg BM	90	Endurance exercise tests	40 ± 6 min	High	Severe	YES/NO	$NaHCO_3$ led to no change in time to exhaustion but higher maximum running speed ($p=0.009$).
Wu et al. 2010	Division 1 tennis players	Fluid solution; 0.3 g/kg BM	90 - 60	Tennis match + skill test	> 50 min	Moderate	N/A	YES	Decline in tennis specific performance decreased after a match with $NaHCO_3$ ($d=1.26$; $p=0.004$).
Mueller et al. 2013	Cyclists / triathletes	Tablet; 0.3 g/kg BM	90	Cycling test	10 - 16 min	High	N/A	YES	$NaHCO_3$ is improves time to exhaustion compared to a placebo (+ 23.5%) ($F_{(1,7)}=35.45$; $p=0.001$ $\eta^2=0.84$).
Egger et al. 2014	Trained cyclists	Fluid solution; 0.3 g/kg BM	120 - 60	Cycling test	< 30 min	Moderate To High	None	YES	Cycling time to exhaustion was improved under $NaHCO_3$ compared to a placebo (ES: 0.6; $p<0.05$)
Krustrup et al. 2015	Trained athletes	Capsule; 0.4 g/kg BM	90, 80, 70, 60, 50	YOYO-IR test	< 10 min	High	N/A	YES	The performance was improved by $NaHCO_3$ (+ 14%) ($p<0.05$).
Marriott et al. 2015	Sub-elite athletes	Capsule; 0.4 g/kg BM	90, 80, 70, 60, 50	Upper body- + YOYO-IR test	17 min + 10 min	High	Mild	YES	$NaHCO_3$ improved YOYO-IR performance by + 23% ($p<0.05$).
Lopes-Silva et al. 2018	Taekwondo athletes	Capsule; 0.3 g/kg BM	90	Taekwondo combat	6 min	Moderate To High	Mild	YES	$NaHCO_3$ increased and sum attack time during taekwondo combat $F_{(1,8)}= 6.11$; $p=0.04$; $\eta^2=0.43$).
Tan et al. 2010	Elite water polo players	Capsule; 0.3 g/kg BM	90	Water polo trial	40 min	Moderate To High	None	NO	No effect on trial performance was detected ($p=0.51$ ES: 0.09±0.23).
Cameron et al. 2010	Rugby union players	Fluid solution; 0.3 g/kg BM	90	Rugby specific sprint test	~ 9 min	Moderate To High	Severe	NO	No improvement on sprint performance which is suspected to be due to GI distress ($p=0.13$).
Kupcis et al. 2012	Lightweight rowers	Capsule; 0.3 g/kg BM	90, 80, 70	2000 m rowing	~ 7 min	High	None	NO	$NaHCO_3$ provides no benefit for rowing performance ($p=0.41$; ES: 0.05).
Hobson et al. 2013	Well-trained rowers	Capsule; 0.3 g/kg BM	120	2000 m rowing	~ 7 min	High	None to Severe	NO	Neither, $NaHCO_3$ and Beta alanine (or combined) have an effect on performance ($p<0.05$)
Hobson et al. 2014	Well-trained rowers	Capsule; 0.3 g/kg BM	120	2000 m rowing	6.25 - 7.30 min	High	None to Severe	NO	Ingestion of $NaHCO_3$ has no effect on rowing performance ($p<0.09$).
Afman et al. 2014	Basketball players	Fluid solution; 0.4 g/kg BM	90, 20	Basketball test	4 x 15 min	Moderate	Moderate	NO	$NaHCO_3$ led to no significant changes in skilled performance test ($F=2.1$; $p=0.1$)

g: Gram; kg: Kilogram; BM: Body mass; min: Minutes; m: Meter; $NaHCO_3$: Sodium Bicarbonate; YOYO-IR: Yo-Yo Intermittent-Recovery Test; N/A: Not applicable; High: Maximum effort; Moderate: Modest effort; Mild: Minimum discomfort; Moderate: Some discomfort, None: No discomfort; Severe: Serious discomfort; ES: Effect size. d= Cohens d; F= Fisher's F test; η^2= eta-squared.

Table 3. **Chronic $NaHCO_3$ supplementation.**

Article	Athletes	Supplementation (type/dose)	Ingestion (min before exercise)	Exercise	Exercise Time	Intensity	Side Effects		Effects of $NaHCO_3$
Durkalec-Michals et al. 2018	Competitive wrestlers	Tablet; progressive regimen: 0.025–0.1 g/kg BM	3 times/day for 10 days	Wingate cycling + wrestling specific test	4 min	High	None	YES/NO	Only time-to-peak power in the second Wingate test was improved with $NaHCO_3$ (f^2=4%; p=0.001).
Tobias et al. 2013	Martial arts athletes	Capsule; 0.5 g/kg BM	4* 0,012g /kg BM/day for 7 days	Upper body Wingate test	2 min	High	Mild	YES	Serial $NaHCO_3$ supplementation enhanced performance by 8% (ES: 1.54; p<0.002).
Oliveira et al. 201	Mixed athletes	Capsule; 0.125 g/kg BM	4 times/day for 5 days	Upper body Wingate test	2 min	High	Mild	YES	$NaHCO_3$ supplementation is effective at improving performance (F=3.4; p=0.02)
Driller et al. 2013	National team rowers	Capsule; 0.3 g/kg BM	2 days/week for 8 weeks	2000 m rowing, HIT test	6.10 – 7 min	High	Mild	NO	Serial supplementation of $NaHCO_3$ before HIT provides no benefits to performance (p>0.05)
Joyce et al. 2012*	Competitive swimmers	Capsule; 0.1 g/kg BM	3 times/day for 3 days	2 x 200 m swim	<2 min	High	Mild	NO	Chronic supplementation of $NaHCO_3$ had no effect on swimming performance (F=0.48; p=0.8).

**paper is displayed twice as acute and chronic supplementation and was investigated separately. Abbreviations: g: Gram; kg: Kilogram; BM: Body mass; min: Minutes; m: Meter; $NaHCO_3$: Sodium Bicarbonate; High: Maximum effort; Mild: Minimum discomfort; None: No discomfort; HIT; High intensity training. f^2: Cohen's f^2; F= Fisher's F test.

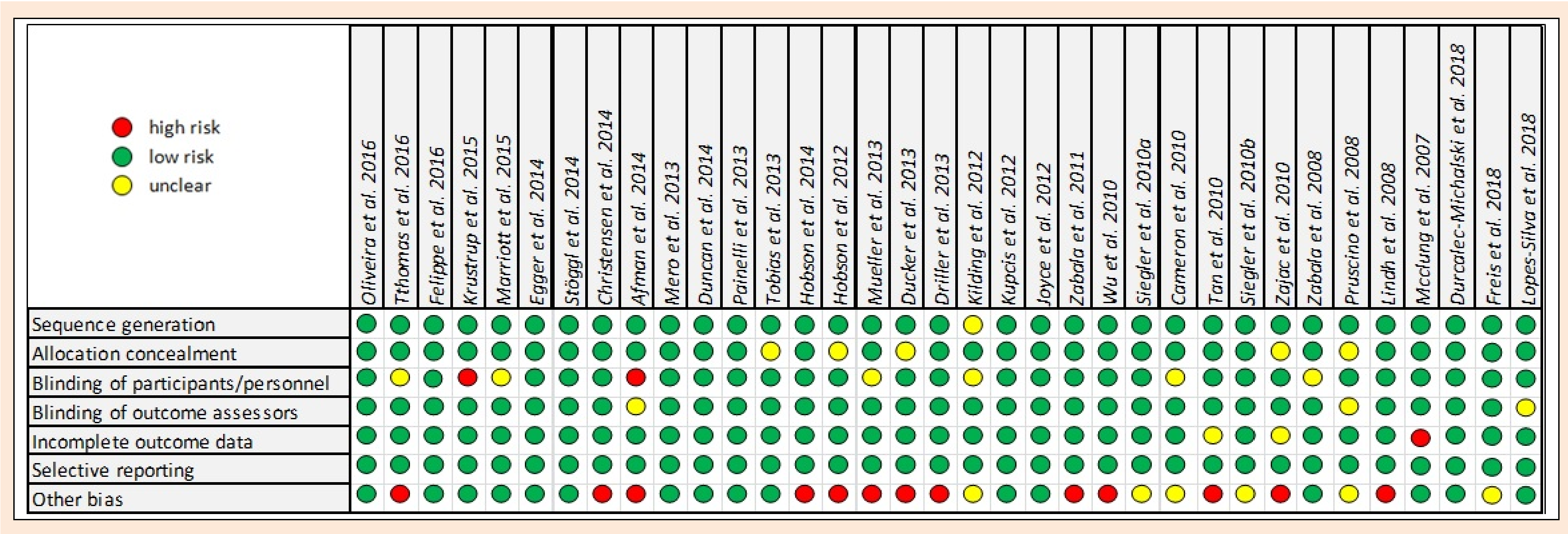

Figure 2. **Cochrane risk of bias assessment.**

Risk of bias assessment

Figure 2 is summarizing the results of the methodological quality assessment across all included studies. An appropriate procedure for a randomly generated sequence was described in all 35 RCTs. Furthermore 30 studies concealed the allocation. A high risk of bias was found in 2 trials regarding blinding of participants and personnel (Afman et al., 2014; Krustrup et al., 2015). One trial was unable to display complete outcome data (McClung and Collins, 2007), 13 out of 35 trials showed high risk of "other bias" not controlling for nutrition intake or GI adverse events during supplementation of $NaHCO_3$.

Effects of $NaHCO_3$

Seventeen out of 35 studies showed performance enhancing effects after supplementing $NaHCO_3$, of which 15 studies supplemented acutely and two chronically. Additionally, six studies showed diverse results by $NaHCO_3$, only increasing one of multiple exercise tasks or outcomes or $NaHCO_3$ only being effective combined with beta-alanine or caffeine.

Regarding the effects of acute supplementation of $NaHCO_3$ under the aspect of exercise duration, 9 studies under four minutes showed favorable effects. Exercise tasks included in these studies were cycling [n=2], swimming [n=4], running [n=2] and boxing [n=1]. In contrary, the results of five studies including swimmers [n=2], cyclist [n=2] and runners [n=1] showed no performance improvements. In addition, three studies demonstrated diverse results containing resistance, judo and swimming exercises (Table 1).

Furthermore, six studies over four minutes showed positive effects of acute $NaHCO_3$ supplementation. Involved trials were cycling [n=2], running [n=2], tennis [n=1] and taekwondo [n=1]. On the other side, six studies with exercise duration of more than four minutes showed no effects while supplementing $NaHCO_3$ acutely. Those were rowing [n=3], basketball [n=1], water polo [n=1], and rugby [n=1]. Two studies using a test lasting six and more than 40 minutes demonstrated diverse results by enhancing rowing performance only in combination with caffeine (Christensen et al., 2014) and significantly improving higher maximum running speed in exhaustive graded exercise while supplementing $NaHCO_3$ (Freis et al., 2017), respectively (Table 2).

Referring to chronic supplementation of $NaHCO_3$, two studies (exercise duration ≤ 4 minutes) showed positive effects. Both included specific upper body exercises (Oliveira et al., 2017; Tobias et al., 2013). In contrast, one study including swimming exercise less than four minutes showed no effect of $NaHCO_3$ (Joyce et al., 2012) and one study including wrestlers showed diverse results by only improving the time-to-peak power in the second Wingate test after $NaHCO_3$ supplementation, but not for the first test (Durkalec-Michalski et al., 2018).

In addition, another study involving rowing exercise with a duration over four minutes resulted in no effect as well (Tobias et al., 2013) (Table 3).

Discussion

The purpose of this systematic review was to investigate the effects of acute or chronic supplementation of $NaHCO_3$ on exercise performances lasting less or more than four minutes in trained athletes. In general, nearly 50% of all RCT's reported positive effects after supplementation. However, we cannot recommend the use of $NaHCO_3$ for enhancing performance in athletes because of the inconsistent and eventually ergolytic results throughout the studies, which are discussed below.

Acute $NaHCO_3$ supplementation and exercise duration ≤ 4 minutes

Out of the 35 studies included in this systematic review seventeen RCT's were acutely supplementing with $NaHCO_3$ during an exercise duration of ≤ 4 minutes. Nine of these studies were clearly showing performance enhancing results after $NaHCO_3$ supplementation. In addition, three trials were showing divergent results even when using the same protocol (Table 1). In these studies $NaHCO_3$ resulted in enhanced performance after supplementation only for one exercise task (Painelli et al., 2013; Duncan et al., 2014) or only in combination with beta-alanine (Painelli et al., 2013) or caffeine (Felippe et al., 2016). While various exercises were tested, greatest results were shown during swimming freestyle (~2.4% performance increase) (Mero et al., 2013; Siegler and Gleadall-Siddall, 2010). Indeed, 2.4% appears small, yet represents 1.1 seconds on a world class level. In reference to the latest FINA world aquatics championships the 1st and the 8th place in the final race of the 100m freestyle were exactly separated by 1.1 seconds.

However, results from these studies must be interpreted carefully, since the participants in the presented studies were elite swimmers but not at a world class level. Thus, the results may not be translatable to top-level athletes and real competition conditions. In addition, it is not clear if $NaHCO_3$ is responsible for these performance improvements because of the inconsistent results throughout other studies even though the same protocols were used.

In contrast to the aforementioned successful results in swimming, two different trials with elite swimmers were unable to show significant improvements, although they used the same supplementation protocol in dosage and delivery of $NaHCO_3$ (Joyce et al., 2012; Pruscino et al., 2008). Furthermore, two other trials involving cycling showed no improvements (Zabala et al., 2011; Zabala et al., 2008). No difference regarding amount, ingestion, type or task of exercise was detected also. Hence, there is an assumption that the level of training (elite- world class athlete) might be influential on the outcome of detecting performance enhancing effects. An earlier systematic review showed that the possible effect of $NaHCO_3$ on exercise performance is lower in trained athletes (Peart et al., 2012). Consequently, it is possible that $NaHCO_3$ is just balancing the deficits between the athletes at different levels. Better trained athletes might have a higher buffering capacity, whereas the lesser trained are more dependent on the additional buffering capacity of the supplement. Therefore, an improved muscle buffering capacity might be more effective than $NaHCO_3$ administration (Peart et al., 2012). In contrast, a more recent review concluded that the benefits of $NaHCO_3$ might be present to a greater extent within trained individuals (McNaughton et al., 2016). This demonstrates the substantial controversy in the literature and the diverse effects of this supplement.

The included studies in this review involved primarily highly trained athletes, whereby their training level is difficult to compare, mostly because of the lacking information or different definitions of athletes in the studies.

Indeed, the huge difference in the studies could provoke the unequal outcomes, even if the same procedures are used. Many studies had a small and heterogeneous group including male and female athletes. Admittedly, the number of female athletes was small but may have influenced the results of the studies, as the potential effect of the menstrual cycle on performance was ignored in all studies involving female athletes (Janse de Jonge, 2003). Another possible influencing factor for the different results may be the presence of a 'high-responders' and 'low-responders' phenomena, which has been reported previously (Tobias et al., 2013; Wu et al., 2010). Furthermore, every study group used different exercises under different conditions which makes comparisons difficult. Another influencing factor causing differences between the studies is the combination of blinding and GI discomfort. In some studies, the blinding efficacy was not proven or could not be guaranteed because of GI distress. When the participants noticed stomach pain or other symptoms, they assumed that they had supplemented $NaHCO_3$. Consequently, this could have led to blinding bias and psychological effects on the outcome. These blinding biases can be seen in the risk of bias assessment (Figure 2). McClung and Collins showed that only believing one had taken the supplement resulted in similar effects as those taking the substance (McClung and Collins, 2007). Finally, all these factors influence the outcome of a study and should be considered carefully when interpreting results.

Acute $NaHCO_3$ supplementation and exercise duration > 4 minutes

Out of 14 RCT's six trials showed a performance enhancement after supplementation and two showed diverse results. Yet, two of these trials detected impressive results by improving running and cycling performance up to 14% (Krustrup et al., 2015) and 23% (Mueller et al., 2013), respectively. Despite these results, six trials amongst rowing, rugby, water polo and basketball did not show performance improvements. In comparison with exercise duration lasting less than four minutes, extended duration (> 4 minutes) appeared to be less successful in increasing performance via $NaHCO_3$, whereby some exceptional cases exist (Krustrup et al., 2015; Tobias et al., 2013; Wu et al., 2010). It appears that the best exercises for performance enhancing effects ought to be short to middle distance high intensity exercises up to a duration of four minutes e.g. swimming (200m), cycling (up to 4km) and running (up to 1500m). These results are in contrast to other authors in the literature claiming benefits of $NaHCO_3$ to be from one to seven minutes (Burke, 2013).

In the current review only two of five studies with an exercise duration of over four to seven minutes resulted in positive effects (Christensen et al., 2014; Lopes-Silva et al., 2018), whereby one of these studies showed significant effects by combining $NaHCO_3$ with caffeine (Christensen et al., 2014). Nevertheless, some cases showed that durations of over 10 (Egger et al., 2014; Mueller et al., 2013; Marriott et al., 2015) to over 50 minutes (Wu et al., 2010; Afman et al., 2014) could be affected by acute $NaHCO_3$ supplementation. Above all, the influence of exercise duration on the performance enhancing effect of $NaHCO_3$ supplementation remains unclear. Because of these inconsistencies in the literature the evidence of exercise duration having an influence on the positive effect of $NaHCO_3$ is not given.

Chronic supplementation

The serial supplementation of $NaHCO_3$ is based on the assumption that chronic manipulation of pH-level may supply a protective effect on mitochondria, which is leading to improved mitochondrial function and consequently improved performance (Driller et al., 2013; Edge et al., 2006). These performance improvements could be seen in multiple events over the same day (Burke, 2013). Furthermore, chronic supplementation of $NaHCO_3$ should reduce the side effects of $NaHCO_3$ ingestion, e.g. GI distress, stomach pain and vomiting because of consuming small doses over several days before the competition (Burke, 2013; Durkalec-Michalski et al., 2018; McNaughton et al., 1999). Two out of five trials of chronic loading of $NaHCO_3$ improved performance and one showed diverse results. In concordance with other results, performance enhancing trials had exercise durations of less than four minutes. Paradoxically, the amounts of consumed $NaHCO_3$ varied massively. It seems that the right amount of $NaHCO_3$ for chronic supplementation is not fully elucidated by present literature. In the current review, the dose varied between 0.025 and 0.5 g/kg BM. Moreover, the time of ingestion and the duration of supplementation were very different. The dosage per day of $NaHCO_3$ varied between one and four times. Furthermore, the duration of supplementation lasted between three to ten days. Consequently, comparisons between these studies are limited.

In 2012 Joyce et al. could not find any improvements in acute nor chronic supplementation protocol in highly-trained swimmers (Joyce et al., 2012). The authors reported similar GI upset under both, acute and chronic supplementation. Consequently, which supplementation protocol (acute vs. chronic) is more effective, cannot be answered, as the results of supplementation with $NaHCO_3$ are ambiguous.

Risk of bias assessment

The included RCT's displayed overall good quality. An inherent but unavoidable issue in trials involving supplements is a high risk of "other Bias". Nutrition is influenced by multiple factors which might influence the effect of exogenous bicarbonate supplementation. In some trials blinding of personnel has not been explained in detail or has not been conducted at all. In addition, food intake before the measurement day was not always reported.

Study limitations

The definition of how the included studies were divided in ≤ 4 or > 4 minutes is an uncommon approach which might have influenced the overall analysis of this systematic review. Nevertheless, due to the general inconsistencies in the implementation of exercise studies and overall heterogeneity in training status of the included individuals between the studies we are convinced that this method was suitable to classify all studies accordingly.

The definition of athletes was based on the description of the participants (national, international, university, elite, college, highly trained or well trained) in the included studies following the definition by Araújo and Scharhag (2016). Unfortunately, the majority of all included studies gave insufficient information about competition or training amount to differentiate between athletes and recreationally trained participants, which might have biased the inclusion- and overall results of this review. Overall, the effect sizes of the included studies were very small and therefore the results should be interpreted carefully when transferred into daily praxis. Furthermore, more databases could have been included in the literature search to increase the numbers of the included studies.

Future research

Athletes and practitioners would benefit if future trials were to focus on elite-athletes to reduce potential day to day variability in performance compared to lower level athletes. Also, the shortcomings in research regarding evidence in disciplines lasting less than 20-25 seconds have to be overcome. Therefore, future trials including elite athletes investigating e.g. Olympic and non-Olympic sprint disciplines are mandatory. Accompanying sprint disciplines, resistance training trials involving maximum repetitions need additional research, as only one trial involving this kind of exercise within the last decade met the inclusion criteria of our search strategy. Finally, more research in acute vs. chronic supplementation should be conducted to find out a correct supplementation protocol.

Conclusion

The duration of exercise might be essential for the supplementation of $NaHCO_3$. However, this cannot be confirmed as the results in the literature are very inconsistent and difficult to compare as different disciplines and varying exercise protocols were applied in the included studies. In addition, results differed even if the same exercise and supplementation protocols were applied. For this reason, small sample sizes and lack of studies showing the exact effects of $NaHCO_3$, substantiated evidence is not given according to the included literature. Also, $NaHCO_3$-induced side effects might have had an ergolytic effect, as few participants showed a decrease in performance following supplementation. Chronic loading protocols may overcome these circumstances yet did not induce mentionable differences in comparison to acute supplementation (Table 1-3). Consequently, it cannot be clarified if supplementation with $NaHCO_3$ results in performance enhancement or simply balancing deficits (buffering capacity) between athletes. Therefore, to which extent the duration of the exercise has on the effects of $NaHCO_3$ remains unclear.

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References

Afman, G., Garside, R.M., Dinan, N., Gant, N., Betts, J.A. and Williams, C. (2014) Effect of carbohydrate or sodium bicarbonate ingestion on performance during a validated basketball simulation test. *International Journal of Sport Nutrition and Exercise Metabolism* **24**, 632–644.

Araújo, C.G.S. and Scharhag, J. (2016) Athlete: a working definition for medical and health sciences research. *Scandinavian Journal of Medicine & Science in Sports* **26(1)**, 4–7.

Barber, J.J., McDermott, A.Y., McGaughey, K.J., Olmstead, J.D. and Hagobian, T.A. (2013) Effects of combined creatine and sodium bicarbonate supplementation on repeated sprint performance in trained men. *Journal of Strength and Conditioning Research* **27(1)**, 252–258.

Burke, L.M. (2013) Practical considerations for bicarbonate loading and sports performance. *Nestle Nutrition Institute Workshop Series* **75**, 15–26.

Cameron, S.L., McLay-Cooke, R.T., Brown, R.C., Gray, A.R. and Fairbairn, K.A. (2010) Increased Blood pH but Not Performance with Sodium Bicarbonate Supplementation in Elite Rugby Union Players. *International Journal of Sport Nutrition and Exercise Metabolism* **20(4)**, 307–321.

Carr, A.J., Hopkins, W.G. and Gore, C.J. (2011a) Effects of acute alkalosis and acidosis on performance: a meta-analysis. *Sports Medicine* **41(10)**, 801–814.

Carr, A.J., Slater, G.J., Gore, C.J., Dawson, B. and Burke, L.M. (2011b) Effect of sodium bicarbonate on HCO3-, pH, and gastrointestinal symptoms. *International Journal of Sport Nutrition and Exercise Metabolism* **21(3)**, 189–194.

Christensen, P.M., Petersen, M.H., Friis, S.N. and Bangsbo, J. (2014) Caffeine, but not bicarbonate, improves 6 min maximal performance in elite rowers. *Applied physiology, nutrition, and metabolism = Physiologie Appliquee, Nutrition et Metabolisme* **39(9)**, 1058–1063.

Close, G.L., Hamilton, D.L., Philp, A., Burke, L.M. and Morton, J.P. (2016) New strategies in sport nutrition to increase exercise performance. *Free Radical Biology & Medicine* **98**, 144–158.

Deb, S.K., Gough, L.A., Sparks, S.A. and McNaughton, L.R. (2018) Sodium bicarbonate supplementation improves severe-intensity intermittent exercise under moderate acute hypoxic conditions. *European Journal of Applied Physiology* **118(3)**, 607–615.

Driller, M.W., Gregory, J.R., Williams, A.D. and Fell, J.W. (2013) The Effects of Chronic Sodium Bicarbonate Ingestion and Interval Training in Highly Trained Rowers. *International Journal of Sport Nutrition and Exercise Metabolism* **23(1)**, 40–47.

Ducker, K.J., Dawson, B. and Wallman, K.E. (2013) Effect of Beta alanine and sodium bicarbonate supplementation on repeated-sprint performance. *Journal of Strength and Conditioning Research* **27(12)**, 3450–3460.

Duncan, M.J., Weldon, A. and 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.

Durkalec-Michalski, K., Zawieja, E.E., Podgórski, T., Zawieja, B.E., Michałowska, P., Łoniewski, I. and Jeszka, J. (2018) The Effect of a New Sodium Bicarbonate Loading Regimen on Anaerobic Capacity and Wrestling Performance. *Nutrients* **10(6)**.

Edge, J., Bishop, D. and Goodman, C. (2006) Effects of chronic NaHCO3 ingestion during interval training on changes to muscle buffer capacity, metabolism, and short-term endurance performance. *Journal of Applied Physiology* **(101)**, 918–925.

Egger, F., Meyer, T., Such, U. and Hecksteden, A. (2014) Effects of Sodium Bicarbonate on High-Intensity Endurance Performance in Cyclists: A Double-Blind, Randomized Cross-Over Trial. *PloS one* **9(12)**, e114729.

Felippe, L.C., Lopes-Silva, J.P., Bertuzzi, R., McGinley, C. and Lima-Silva, A.E. (2016) Separate and Combined Effects of Caffeine and Sodium-Bicarbonate Intake on Judo Performance. *International journal of Sports Physiology and Performance* **11(2)**, 221–226.

Freis, T., Hecksteden, A., Such, U. and Meyer, T. (2017) Effect of sodium bicarbonate on prolonged running performance: A randomized, double-blind, cross-over study. *PloS one* **12(8)**, e0182158.

Gough, L.A., Deb, S.K., Sparks, A. and McNaughton, L.R. (2017) The Reproducibility of 4-km Time Trial (TT) Performance Following Individualised Sodium Bicarbonate Supplementation: a Randomised Controlled Trial in Trained Cyclists. *Sports Medicine - open* **3(1)**, 34.

Helgerud, J., Høydal, K., Wang, E., Karlsen, T., Berg, P., Bjerkaas, M., Simonsen, T., Helgesen, C., Hjorth, N., Bach, R. and Hoff, J. (2007) Aerobic high-intensity intervals improve VO2max more than moderate training. *Medicine and Science in Sports and Exercise* **39(4)**, 665–671.

Higgins, J.P.T., Altman, D.G., Gotzsche, P.C., Juni, P., Moher, D., Oxman, A.D., Savovic, J., Schulz, K.F., Weeks, L. and Sterne, J.A.C. (2011) The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ* **343(oct18 2)**, d5928-d5928.

Hobson, R.M., Harris, R.C., Martin, D., Smith, P., Macklin, B., Elliott-Sale, K.J. and Sale, C. (2014) Effect of sodium bicarbonate supplementation on 2000-m rowing performance. *International Journal of Sports Physiology and Performance* **(9)**, 139–144.

Hobson, R.M., Harris, R.C., Martin, D., Smith, P., Macklin, B., Gualano, B. and Sale, C. (2013) Effect of Beta-Alanine with and without Sodium Bicarbonate on 2,000-m Rowing Performance. *International Journal of Sport Nutrition and Exercise Metabolism* **23(5)**, 480–487.

Hofmann, P. and Tschakert, G. (2010) Special needs to prescribe exercise intensity for scientific studies. *Cardiology Research and Practice* **2011**, 209302.

Janse de Jonge, X.A.K. (2003) Effects of the Menstrual Cycle on Exercise Performance. *Sports Medicine* **33(11)**, 833–851.

Joyce, S., Minahan, C., Anderson, M. and Osborne, M. (2012) Acute and chronic loading of sodium bicarbonate in highly trained swimmers. *European Journal of Applied Physiology* **112(2)**, 461–469.

Kilding, A.E., Overton, C. and Gleave, J. (2012) Effects of Caffeine, Sodium Bicarbonate, and Their Combined Ingestion on High-Intensity Cycling Performance. *International Journal of Sport Nutrition and Exercise Metabolism* **22(3)**, 175–183.

Krustrup, P., Ermidis, G. and Mohr, M. (2015) Sodium bicarbonate intake improves high-intensity intermittent exercise performance in trained young men. *Journal of the International Society of Sports Nutrition* **12**, 25.

Kupcis, P.D., Slater, G.J., Pruscino, C.L. and Kemp, J.G. (2012) Influence of Sodium Bicarbonate on Performance and Hydration in Lightweight Rowing. *International Journal of Sports Physiology and Performance* **7(1)**, 11–18.

Lindh, A.M., Peyrebrune, M.C., Ingham, S.A., Bailey, D.M. and Folland, J.P. (2008) Sodium bicarbonate improves swimming performance. *International Journal of Sports Medicine* **29(6)**, 519–523.

Lopes-Silva, J.P., Da Silva Santos, J.F., Artioli, G.G., Loturco, I., Abbiss, C. and Franchini, E. (2018) Sodium bicarbonate ingestion increases glycolytic contribution and improves performance during simulated taekwondo combat. *European Journal of Sport Science* **18(3)**, 431–440.

Marriott, M., Krustrup, P. and Mohr, M. (2015) Ergogenic effects of caffeine and sodium bicarbonate supplementation on intermittent exercise performance preceded by intense arm cranking exercise. *Journal of the International Society of Sports Nutrition* **12**, 13.

McClung, M. and Collins, D. (2007) "Because I know It will!": Placebo Effects of an Ergogenic Aid on Athletic Performance. *Journal of Sport and Exercise Psychology* **29(3)**, 382–394.

McNaughton, L., Backx, K., Palmer, G. and Strange, N. (1999) Effects of chronic bicarbonate ingestion on the performance of high-intensity work. *European Journal of Applied Physiology and Occupational Physiology* **80(4)**, 333–336.

McNaughton, L.R. (1992) Sodium bicarbonate ingestion and its effects on anaerobic exercise of various durations. *Journal of Sports Sciences* **10(5)**, 425–435.

McNaughton, L.R., Gough, L., Deb, S., Bentley, D. and Sparks, S.A. (2016) Recent Developments in the Use of Sodium Bicarbonate as an Ergogenic Aid. *Current Sports Medicine Reports* **15(4)**, 233–244.

Mero, A.A., Hirvonen, P., Saarela, J., Hulmi, J.J., Hoffman, J.R. and Stout, J.R. (2013) Effect of sodium bicarbonate and beta-alanine supplementation on maximal sprint swimming. *Journal of the International Society of Sports Nutrition* **10(1)**, 52.

Mueller, S.M., Gehrig, S.M., Frese, S., Wagner, C.A., Boutellier, U. and Toigo, M. (2013) Multiday acute sodium bicarbonate intake improves endurance capacity and reduces acidosis in men. *Journal of the International Society of Sports Nutrition* **10(1)**, 16.

Oliveira, L.F., Salles Painelli, V.d., Nemezio, K., Gonçalves, L.S., Yamaguchi, G., Saunders, B., Gualano, B. and Artioli, G.G. (2017) Chronic lactate supplementation does not improve blood buffering capacity and repeated high-intensity exercise. *Scandinavian Journal of Medicine & Science in Sports* **(27)**, 1231–1239.

Painelli, V.d.S., Roschel, H., Jesus, F.d., Sale, C., Harris, R.C., Solis, M.Y., Benatti, F.B., Gualano, B., Lancha, A.H. and Artioli, G.G. (2013) The ergogenic effect of beta-alanine combined with sodium bicarbonate on high-intensity swimming performance. *Applied Physiology, Nutrition, and Metabolism* **38(5)**, 525–532.

Peart, D.J., Siegler, J.C. and Vince, R.V. (2012) Practical recommendations for coaches and athletes: a meta-analysis of sodium bicarbonate use for athletic performance. *Journal of Strength and Conditioning Research* **26(7)**, 1975–1983.

Pruscino, C.L., Ross, M.L.R., Gregory, J.R., Savage, B. and Flanagan, T.R. (2008) Effects of Sodium Bicarbonate, Caffeine, and Their Combination on Repeated 200-m Freestyle Performance. *International Journal of Sport Nutrition and Exercise Metabolism* **18(2)**, 116–130.

Saunders, B., Sale, C., Harris, R.C. and Sunderland, C. (2014) Sodium bicarbonate and high-intensity-cycling capacity: variability in responses. *International Journal of Sports Physiology and Performance* **9**, 627–632.

Siegler, J.C. and Gleadall-Siddall, D.O. (2010) Sodium bicarbonate ingestion and repeated swim sprint performance. *Journal of Strength and Conditioning Research* **24(11)**, 3105–3111.

Siegler, J.C. and Hirscher, K. (2010) Sodium bicarbonate ingestion and boxing performance. *Journal of Strength and Conditioning Research* **24(1)**, 103–108.

Siegler, J.C., Marshall, P.W.M., Bishop, D., Shaw, G. and Green, S. (2016) Mechanistic Insights into the Efficacy of Sodium Bicarbonate Supplementation to Improve Athletic Performance. *Sports Medicine - Open* **2(1)**, 41.

Stöggl, T., Torres-Peralta, R. and Cetin, E. (2014) *Repeated high intensity bouts with long recovery: Are bicarbonate or carbohydrate supplements an option?. The Scientific World Journal, vol 2014, Article ID 145747, 8 pages.*

Talbott, J.H., Edwards, H.T. and Dill, D.B. (1931) Effect of acidosis and alkalosis upon capacity for work. *Journal of Clinical Investigation* **9**, 601–613.

Tan, F., Polglaze, T., Cox, G., Dawson, B., Mujika, I. and Clark, S. (2010) Effects of Induced Alkalosis on Simulated Match Performance in Elite Female Water Polo Players. *International Journal of Sport Nutrition and Exercise Metabolism* **20(3)**, 198–205.

Thomas, C., Delfour-Peyrethon, R., Bishop, D.J., Perrey, S., Leprêtre, P.-M., Dorel, S. and Hanon, C. (2016) Effects of pre-exercise alkalosis on the decrease in VO2 at the end of all-out exercise. *European Journal of Applied Physiology* **116(1)**, 85–95.

Tobias, G., Benatti, F.B., Salles Painelli, V. de, Roschel, H., Gualano, B., Sale, C., Harris, R.C., Lancha, A.H. and Artioli, G.G. (2013) Additive effects of beta-alanine and sodium bicarbonate on upper-body intermittent performance. *Amino Acids* **45(2)**, 309–317.

Tschakert, G., Kroepfl, J., Mueller, A., Moser, O., Groeschel, W. and Hofmann, P. (2015) How to Regulate the Acute Physiological Response to " Aerobic " High-Intensity Interval Exercise. *Journal of Sports Science and Medicine* **(14)**, 29–36.

Wisløff, U., Støylen, A., Loennechen, J.P., Bruvold, M., Rognmo, Ø., Haram, P.M., Tjønna, A.E., Helgerud, J., Slørdahl, S.A., Lee, S.J., Videm, V., Bye, A., Smith, G.L., Najjar, S.M., Ellingsen, Ø. and Skjaerpe, T. (2007) Superior cardiovascular effect of aerobic interval training versus moderate continuous training in heart failure patients: a randomized study. *Circulation* **115(24)**, 3086–3094.

Wu, C.-L., Shih, M.-C., Yang, C.-C., Huang, M.-H. and Chang, C.-K. (2010) Sodium bicarbonate supplementation prevents skilled tennis performance decline after a simulated match. *Journal of the International Society of Sports Nutrition* **7**, 33.

Zabala, M., Peinado, A.B., Calderón, F.J., Sampedro, J., Castillo, M.J. and Benito, P.J. (2011) Bicarbonate ingestion has no ergogenic effect on consecutive all out sprint tests in BMX elite cyclists. *European Journal of Applied Physiology* **111(12)**, 3127–3134.

Zabala, M., Requena, B., Sánchez-Muñoz, C., González-Badillo, J.J., García, I., Oöpik, V. and Pääsuke, M. (2008) Effects of sodium bicarbonate ingestion on performance and perceptual responses in a laboratory-simulated BMX cycling qualification series. *Journal of Strength and Conditioning Research* **22(5)**, 1645–1653.

Zajac, A., Cholewa, J., Poprzecki, S., Waskiewicz, Z. and Langfort, J. (2009) Effects of sodium bicarbonate ingestion on swim performance in youth athletes. *Journal of Sports Science and Medicine* **8(1)**, 45–50.

Key points

- Duration of exercise might be essential for the supplementation of sodium bicarbonate, but to which extent remains unclear
- Substantiated evidence for supplementing sodium bicarbonate cannot be given because of small sample sizes and lack of studies showing the exact effects of $NaHCO_3$ in the existing literature
- Chronic loading protocols may overcome the ergolytic effects yet did not induce mentionable differences in comparison to acute supplementation

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