Sodium bicarbonate supplementation and the female athlete: a brief commentary with small scale systematic review and meta-analysis.

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Sodium bicarbonate supplementation and the female athlete: A brief commentary with small scale systematic review and meta-analysis

Running head: Sodium bicarbonate and the female athlete

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ABSTRACT

Sodium bicarbonate (SB) is considered an effective ergogenic supplement for improving high-intensity exercise capacity and performance, although recent data suggests that women may be less amenable to its ergogenic effects than men. Currently, an apparent paucity of data on women means no consensus exists on whether women benefit from SB supplementation. The aim of the current study was to quantify the proportion of the published literature on SB supplementation that includes women, and to synthesise the evidence regarding its effects on blood bicarbonate and exercise performance in women by performing a systematic review and meta-analysis. Electronic searches of the literature were undertaken using three databases (MEDLINE, Embase, SPORTDiscus) to identify relevant articles. All meta-analyses were performed within a Bayesian framework. A total of 149 SB articles were identified, 11 of which contained individual group data for women. Results indicated a pooled blood bicarbonate increase of 7.4 [95%CrI: 4.2 to 10.4 $mmol \cdot L^{-1}$] following supplementation and a pooled standardised exercise effect size of 0.37 [95%CrI: -0.06 to 0.92]. The SB literature is skewed, with only 20% (30 studies) of studies employing female participants, of which only 11 studies (7.4%) provided group analyses exclusively in women. Despite the small amount of available data, results are consistent in showing that SB supplementation in women leads to large changes in blood bicarbonate and that there is strong evidence for a positive ergogenic effect on exercise performance that is likely to be small to medium in magnitude.

Keywords: Ergogenic aid, anaerobic capacity, acidosis, glycolysis, sex differences, high-intensity exercise.

Introduction

Sodium bicarbonate is considered an effective ergogenic supplement (Maughan et al., 2018), with repeated meta-analytical data supporting its use for improving high-intensity exercise capacity and performance (Carr, Hopkins, & Gore, 2011; Christensen, Shirai, Ritz, & Nordsborg, 2017; Matson & Tran, 1993; Peart, Siegler, & Vince, 2012). This is due to an increase in blood pH and circulating bicarbonate concentration (*i.e.*, alkalosis) following ingestion, augmenting the buffering potential of the body. This increased buffering capacity can improve control of exercise-induced metabolic acidosis, characterized by hydrogen ion (H^+) accumulation that is detrimental to exercise performance due to its interference with several metabolic and contractile processes (Allen, Lamb, & Westerblad, 2008; Fitts, 1994; Jarvis, Woodward, Debold, & Walcott, 2018; Sundberg, Hunter, Trappe, Smith, & Fitts, 2018).

A number of factors may moderate the effect of SB supplementation on exercise outcomes, including supplement dose, timing and training status (Heibel, Perim, Oliveira, McNaughton, & Saunders, 2018). However, little is currently known about whether sex influences the response to SB supplementation, although this seems plausible given evidence that women have a lower tolerance for high-intensity exercise performance than men (Russ, Lanza, Rothman, & Kent-Braun, 2005) likely due in part to less overall muscle mass (Hegge et al., 2016; Janssen, Heymsfield, Wang, & Ross, 2000) and lower type II muscle fibre distribution (Porter, Stuart, Boij, & Lexell, 2002; Simoneau & Bouchard, 1989). Findings demonstrate women also have a lower overall capacity for glycolysis due to lower glycolytic enzyme activity (Green, Fraser, & Ranney, 1984), leading to less acidosis (Russ, Lanza, Rothman, & Kent-Braun, 2005). Theoretically, this could mean that women may have a smaller response to a buffering agent intended to improve high-intensity exercise performance. A recent study supports this theory showing an improvement in Wingate and wrestling specific performance

following SB supplementation in men, but not women (Durkalec-Michalski, Zawieja, Zawieja, Michalowska, & Podgorski, 2020). These results imply a potential sex dysmorphism that the authors attributed to the aforementioned differences in anaerobic capacities. Carr et al. (2011) previously showed unclear evidence of a modifying of sex for SB while conflicting evidence regarding the efficacy of SB to improve exercise outcomes in women exists, with both positive (Delextrat et al., 2018; McNaughton, Ford, & Newbold, 1997) and null (Macutkiewicz & Sunderland, 2018; Voskamp, van den Bos, Foster, de Koning, & Noordhof, 2020) results reported. These inconsistent findings appear to contrast with the strong evidence of a positive effect previously reported in studies with predominantly male participants (Carr et al., 2011; Christensen et al., 2017; Matson & Tran, 1993; Peart et al., 2012). Disparity in the quantity of data available for women compared to men might contribute to the current uncertainty and it is important to quantify and summarise current evidence for SB in women. Therefore, the aim of the current study was to quantify the proportion of the published literature on SB supplementation that includes women and to synthesise the evidence regarding its ergogenic effect on women, using a systematic review and meta-analytic approach.

Methods

Study Eligibility

The protocol for this study was designed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher, Liberati, Tetzlaff, Altman, & Group, 2009) and the research question determined with reference to PICOS (Population, Intervention, Comparator, Outcomes and Study Design). The study was not pre-registered. Initially, the literature was screened to identify all SB supplementation studies with both male and female ***populations***. This broader screening strategy was used to identify the proportion of the total evidence base that employed female participants. The data extraction and meta-analysis was subsequently based only on those studies that included a group consisting of women only. The ***intervention*** must have employed an acute (<1 day) or chronic (>1 day) supplementation protocol with SB prior to performing an exercise test. The ***comparator*** for the meta-analysis determined that only single or double-blinded, placebo-controlled studies were included. Studies that reported on ***outcomes*** based on exercise performance and capacity tests were considered for inclusion (Saunders et al., 2017) and ***study design*** allowed both crossover and parallel group designs. Only peer-reviewed, English language, original human studies were included.

Search Strategy

An electronic search of the literature was undertaken using three databases (MEDLINE, Embase, SPORTDiscus) to identify relevant articles. The search was originally conducted to inform a systematic review and meta-analysis on the use of extracellular buffers on exercise outcomes. The search terms “sodium bicarbonate”, “sodium citrate”, “calcium lactate”, “sodium lactate” and “alkalosis” were individually concatenated with “supplementation”, “exercise”, “training”, “athlete” and “performance”. Following duplicate removal, a 2-phase

search strategy (title/abstract; full text) was employed by two independent reviewers (LFO and ED) using freely available software – Rayyan QCRI (Ouzzani, Hammady, Fedorowicz, & Elmagarmid, 2016). A final search was completed in February 2020.

Certainty in cumulative outcomes

Certainty in blood and exercise outcomes was determined according to the framework provided by the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) working group (Guyatt et al., 2008). This approach considers eight factors to determine the level of certainty in outcomes, five of which can be used to downgrade certainty in outcomes (risk of bias, imprecision, inconsistency, indirectness and publication bias), while potential upgrading factors can include large effects; evidence of dose-response or the presence of plausible residual confounding factors. All studies in the current review were initially defined as "high" because they were all randomized, blinded, placebo-controlled trials. This *a-priori* rating was either maintained, or downgraded following application of the strategy, allowing certainty in outcomes to be graded as "high", "moderate", "low" or "very low". Risk of bias was assessed using the most recent Cochrane tool for assessing risk of bias in randomized trials (RoB 2) (Sterne et al., 2019). Evaluation of risk of bias was performed in a blinded fashion by a single reviewer (LFO) and verified by a second reviewer (BS).

Data Extraction

Data extraction was completed by a single reviewer (LFO) using a standardised and pre-piloted data extraction form with Microsoft Excel, and the extraction was verified by a second reviewer (BS). The following information was extracted: (i) author and publication year, (ii) study design; (iii) sample population; (iv) intervention protocol; (v) exercise protocol (vi) blood and exercise outcome data. Where numerical data were not directly available, blood (Bishop &

Claudius, 2005; Bishop, Edge, Davis, & Goodman, 2004; Kozak-Collins, Burke, & Schoene, 1994; Tan et al., 2010) data were extracted from figures using digitizing software (DigitizeIt; (Rakap, Rakap, Evran, & Cig, 2016). To avoid duplication bias, when an exercise protocol resulted in multiples outcome measures of the same exercise test, a solitary outcome measure was extracted based upon the following hierarchy: i) total work done; ii) mean output throughout the test (*i.e.,* mean power output; mean velocity; mean height); time-to-completion (performance test)/time to exhaustion (capacity test).

Statistical Analysis

All meta-analyses (performed by PAS) were conducted within a Bayesian framework to provide a more flexible modelling approach and enable results to be interpreted intuitively through reporting of subjective probabilities (Kruschke & Liddell, 2018). The first meta-analysis pooled group pre- and post-supplement blood bicarbonate data, with placebo-controlled mean change effect sizes used to summarise findings reported in the actual units of measurement. The second meta-analysis pooled group exercise performance data, with effect sizes calculated by standardising the mean difference in the supplementation and placebo conditions by the placebo standard deviation. Sampling variances of effect sizes required an estimate of the correlation between paired data that are generally not provided in studies. To account for this, an initial estimate was made assuming a correlation of 0.7 and an informative Gaussian prior approximating a correlation between 0.5 and 1 were included. A correction for small sample sizes was applied for both the effect size and its within study variance (Morris & DeShon, 2002). To investigate the potential for a moderating effect of exercise duration, binary exercise test categories were created (<30 s, ≥30 s; (Saunders et al., 2017)). Three-level meta-analytic models were used to account for the inclusion of multiple outcomes within a single study (Van den Noortgate, Lopez-Lopez, Marin-Martinez, & Sanchez-Meca, 2013).

Inferences were performed on posterior samples generated using the Hamiltonian Markov Chain Monte Carlo method, reporting median values and 95% credible intervals (CrIs). Heterogeneity in the data was quantified by the between study variance parameter which in Bayesian meta-analysis includes uncertainty described by the CrI. Additionally, probabilities were calculated for pooled effect sizes exceeding the threshold of 5 $mmol \cdot L^{-1}$ [*P*(Increase > 5)] for blood bicarbonate (Jones et al., 2016); and exceeding effect sizes (ES) of 0, 0.2 and 0.5 (zero, small and medium) [P(Increase > ES)] for exercise outcomes. Probabilities were calculated using the posterior samples of the parameters and the proportion of values exceeding the specified threshold. Due to the small number of data points and potential for small-study effects, sensitivity analyses were completed using robust meta-analyses with random effect fitted with a t-distribution. Funnel plots were not explored due to limited data and consistency across study sample sizes. Analyses were performed using the R wrapper package brms interfaced with Stan to perform sampling (Bürkner, 2017).

Results

Study search

A total of 149 SB articles were identified following the search and filter (Figure 1), of which 113 (76%) recruited men only and 9 (6%) women only. A total of 21 studies (14%) recruited both men and women, 2 of which separated according to sex for analyses, and 19 of which did not, grouping data for both men and women. Six (4%) studies did not specify the sex of their participants. This resulted in a total of 1175 men and 134 women analysed separately. Studies that analysed men and women together comprised 273 individuals, of which 195 were men and 78 were women. Of the 30 studies including women, only one reported information relating to the menstrual cycle or contraceptive use of the participants (Macutkiewicz & Sunderland, 2018), with the same study the only to control for menstrual cycle phase during the testing period. Only 11 studies with standalone female groups were taken forward to the meta-analysis.

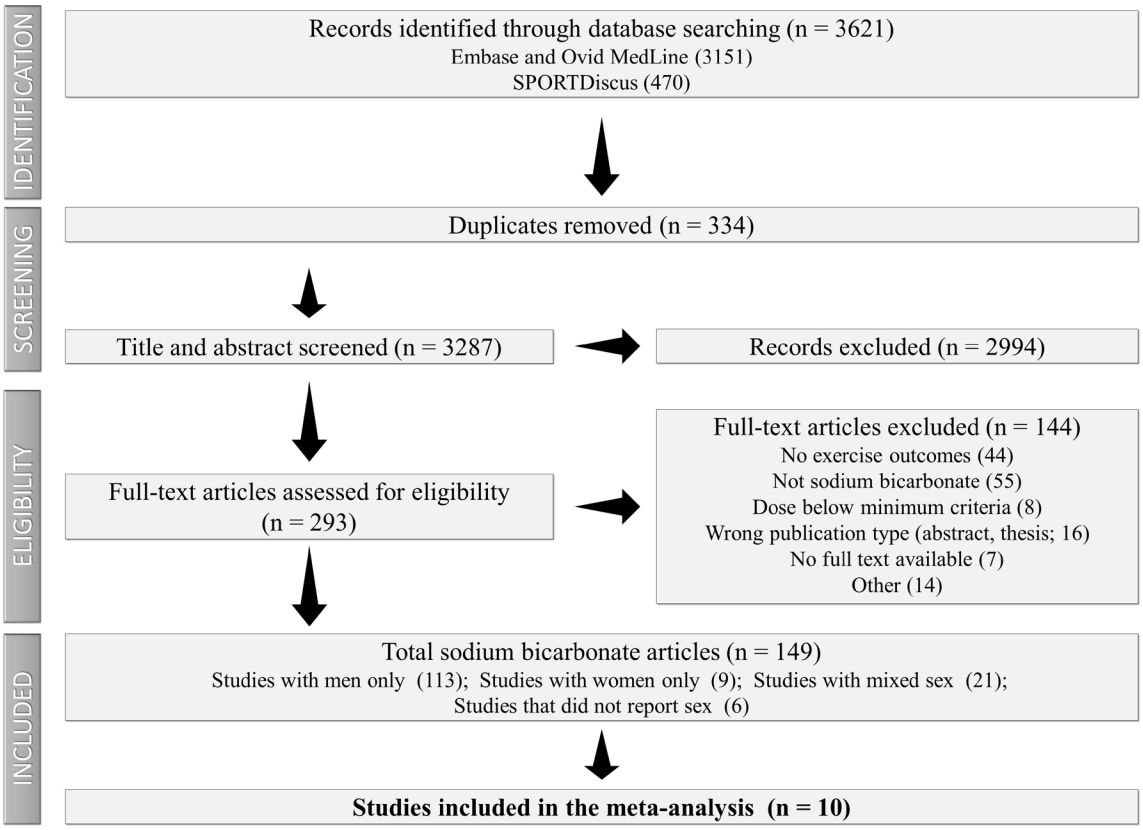

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines flow chart for literature search and study selection.

Meta-analysis

Data from ten studies that contained separate data for women were included in the meta-analysis (Table 1). One parallel group study was not included in the analysis since it involved chronic SB or placebo supplementation in female students prior to interval training performed three times per week for eight weeks, but did not involve supplementation prior to the exercise outcome test (Edge, Bishop, & Goodman, 2006).

Blood bicarbonate

Blood bicarbonate data were available from four studies (Bishop & Claudius, 2005; Bishop, Edge, & Goodman, 2004; McNaughton et al., 1997; Tan et al., 2010) totalling 39 participants. Results indicated a pooled blood bicarbonate increase of 7.4 [95%CrI: 4.2 to 10.4 $mmol \cdot L^{-1}$; $P(\text{Increase} > 5) = 0.937$] following supplementation. The between study variance was 3.7

[95%CrI: 2.2 to 7.8 mmol·L^{-1}]. Median values and probabilities remained unchanged in the sensitivity analysis conducted with all data points and robust variance estimation.

Exercise data

Twelve exercise outcomes were obtained from ten studies (Bishop & Claudius, 2005; Bishop, Edge, Davis, et al., 2004; Delextrat et al., 2018; Durkalec-Michalski et al., 2020; Macutkiewicz & Sunderland, 2018; McNaughton et al., 1997; Tan et al., 2010; Tiryaki & Atterbom, 1995; Voskamp et al., 2020) totalling 109 participants. Results indicated a pooled standardised effect size of 0.37 [95%CrI: -0.06 to 0.92; *P*(Increase > 0) = 0.962; *P*(Increase > 0.2) = 0.784; *P*(Increase > 0.5) = 0.263; Figure 2] and a between study variance of 0.38 [95%CrI: 0.02 to 1.2]. Sensitivity analysis with the robust t-distribution to account for the small number of data points and existence of some large individual effects sizes estimated a slightly smaller pooled effect size 0.29 [95%CrI: -0.07 to 0.84; *P*(Increase > 0) = 0.949; *P*(Increase > 0.2) = 0.689; *P*(Increase > 0.5) = 0.191]. Meta-regression provided no substantive evidence of a moderating effect of exercise duration, with the estimated difference between short (<30 s; 5 studies, n=54) and longer duration (≥30 s; 6 studies, n=71) exercise tests estimated to be 0.02 [95%CrI: -0.52 to 0.55; P(Difference > 0) = 0.526].

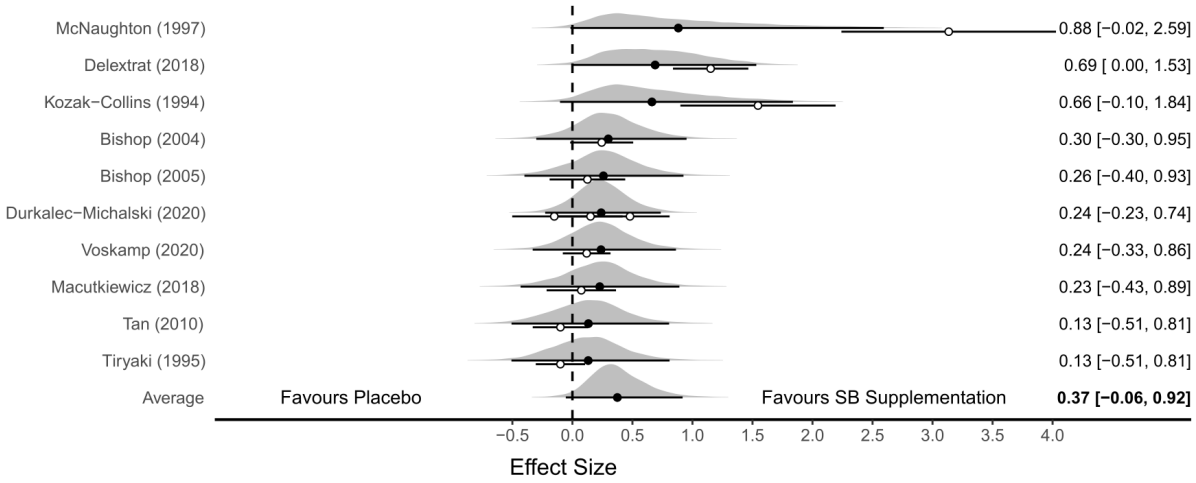

Figure 2. Bayesian Forest Plot of effect sizes for sodium bicarbonate (SB) supplementation on exercise performance. Distributions represent "shrunken estimates" based on all effects size obtained from the study, the random effects model fitted and borrowed information across studies to reduce uncertainty. Black circles and connected intervals represent the median value and 95% credible intervals for the shrunken estimates. White circles and intervals represent the raw estimates and sampling variance calculated directly from study data.

Certainty in cumulative outcomes

Blood and exercise outcomes were assigned an *a-priori* certainty rating of "high" because they were all based on data from blinded, randomized, placebo-controlled trials (as defined by the eligibility criteria). All studies included in the meta-analysis were classified as having "some concerns" according to ROB2 (Figure 3). Three studies had some concerns in Domain 4 (Measurement of the outcome) due to a lack of familiarisation to the protocol (Kozak-Collins et al., 1994; McNaughton et al., 1997) or a non-double-blind study design (Macutkiewicz & Sunderland, 2018). All studies were classified as having some concerns due to a lack of a pre-specified analysis plan (as outlined in Domain 5). This was not deemed to pose an undue risk to either outcome measure, thus no outcome was downgraded based on risk of bias (Supplementary Table 1).

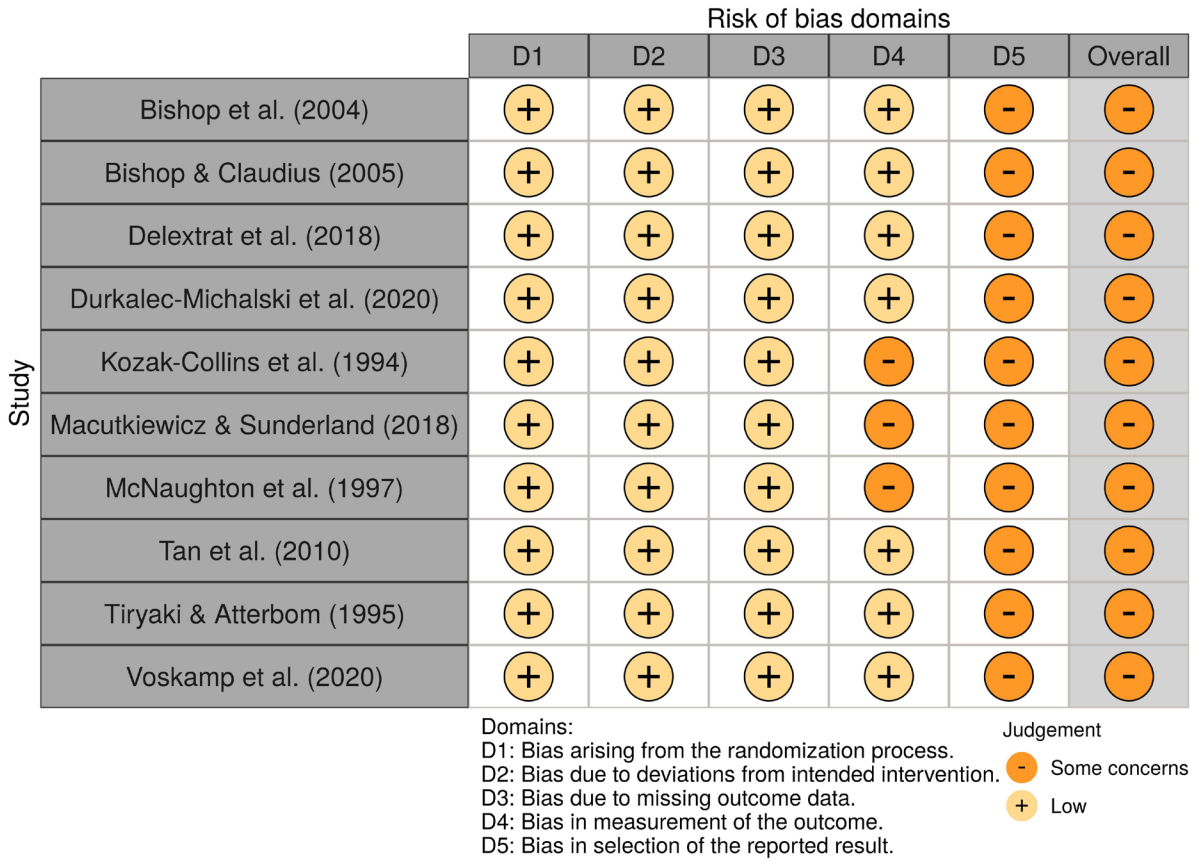

Figure 3. Risk of bias assessment of the ten studies included in the meta-analysis. (Plot was created using *robvis* (McGuinness & Higgins, 2020) and are in a colourblind-friendly colour scheme).

Both blood and exercise outcomes were downgraded for imprecision due to low numbers of outcome measures (four for blood, 12 for exercise). Consistent blood and exercise effects meant no measure was downgraded for inconsistency. Almost all studies were performed in young, trained women with commonly employed dosing strategies and, thus, deemed to have direct, real-life applicability for the female athlete and were not downgraded for indirectness. Nonetheless, downgrading of certainty based on indirectness may be advisable for those interested in other populations (*e.g.*, middle-aged, or elderly populations) or exercise outcomes (*e.g.*, resistance/strength exercise). Publication bias was not explored due to limited data and consistency across study sample sizes, meaning no outcome was downgraded for this domain but future meta-analyses with a larger number of studies will allow this to be ascertained. Blood outcomes were upgraded according to GRADE recommendations because they were consistent

261 with previous meta-analytic results based on the blood bicarbonate response to SB
262 supplementation (Carr et al., 2011) and align with evidence-based and plausible physiological
263 mechanisms. Certainty in exercise outcomes were not upgraded. Thus, certainty in blood
264 outcomes was considered high, and certainty in exercise outcomes considered moderate
265 (Supplementary Table 1).

Discussion

The SB literature is skewed regarding investigations in women, with only 20% (30 studies) of studies employing female participants, of which only 11 studies (7.4%) provided group analyses exclusively in women. Despite the small amount of available data, results are consistent in showing that SB supplementation in women leads to large changes in blood bicarbonate and that there is strong evidence for a positive ergogenic effect on exercise performance [$P(\text{Increase} > 0) = 0.962$]. Due to the small amount of data available and the substantive heterogeneity, it was not possible to obtain a precise estimate of the pooled effect size for exercise performance. However, the analyses suggest the effect is most likely to be between small and moderate.

Research on exercise physiology and nutritional supplements in women is notoriously scarce (Burke, 2017; O'Halloran, 2020), and the SB literature is no different with only 11 of 149 studies including a standalone female group. Across the whole research base comprising men and women, strong evidence exists to support the use of SB to improve exercise outcomes as demonstrated by multiple meta-analyses (Carr et al., 2011; Christensen et al., 2017; Matson & Tran, 1993; Peart et al., 2012). The current meta-analytical data restricted to female participants and based on nine crossover studies and one parallel group design comprising 118 participants is consistent with previous evidence. Whilst uncertainty in the pooled effect size was high due to the limited number of data points and substantive heterogeneity across studies, the probability that the pooled effect size was small or above was estimated to be around 78%, and the median standardised estimate of 0.37 is consistent with previous research conducted with predominantly male participants (0.36 – 0.44) (Christensen et al., 2017; Matson & Tran, 1993; Peart et al., 2012).

The recent data of Durkalec-Michalski et al. (2020) showed that SB supplementation improved wrestling specific performance in men, but not women. The authors speculated that physiological factors that might explain these divergent responses include differences in muscle fibre type and anaerobic capacity. Women typically have less overall muscle mass (Hegge et al., 2016; Janssen et al., 2000), type II muscle fibres (Porter et al., 2002; Simoneau & Bouchard, 1989) and lower glycolytic capacity (Green et al., 1984; Russ et al., 2005; Tarnopolsky, 2000), meaning they might be less susceptible to performance affecting decreases in muscle pH and, thus, also less susceptible to performance improvements with increased buffering capacity. The results of this study contrast with this hypothesis and the results of Durkalec-Michalski et al. (2020) and suggest that women do benefit from SB supplementation. This discrepancy might be due to a low sample size in Durkalec-Michalski et al. (2020) which was potentially unable to detect small differences in performance of these exercise tests. The number of women in their study was almost half that of men (18 vs. 33), and although women showed no improvements while men did, performance changes for women appear similar to those of men (Figure 3 of the original article).

Some evidence indicates that menstrual cycle phase may impact anaerobic exercise capacity, with reduced performance previously observed in the early follicular phase of the menstrual cycle (Masterson, 1999), although other studies failed to replicate this finding (Bushman, Masterson, & Nelsen, 2006; Sunderland & Nevill, 2003; Sunderland, Tunaley, Horner, Harmer, & Stokes, 2011). Greater evidence for no effect of menstrual cycle is consistent with recent meta-analytic data that indicated that exercise test performance may be only trivially reduced during the early follicular phase of the menstrual cycle (McNulty et al., 2020), although it is important to highlight that the observed effect was very small, and varied widely across studies. Nonetheless, these data indicating a potential difference in exercise performance

across the menstrual cycle could also be taken to imply that the efficacy of ergogenic aids intended to enhance exercise test performance may also be impacted by menstrual cycle phase, particularly at the individual level. Despite this, only one of the 11 studies included within this review reported information relative to menstrual cycle/contraceptive use and to standardisation of tests (or not) according to menstrual cycle phase. Macutkiewicz and Sunderland (2018) reported that seven of their eight participants had normal menstrual cycles while one had been taking an oral contraceptive for over a year. The two experimental trials in this study were conducted during days 4-14 of the follicular phase or during days 5–20 of resuming the oral contraceptive pill. This was verified by measuring plasma progesterone concentrations, which were not different between trials, although it is important to highlight that progesterone levels remain relatively stable during the follicular phase of the menstrual cycle, whereas oestrogen increases rapidly meaning that different oestrogen concentrations between trials cannot be ruled out. Currently, no information exists as to whether menstrual cycle phase would alter the physiological and exercise responses to SB supplementation. However, considering the effects of ergogenic supplements are generally small, even very small changes in exercise capacity during different phases of the menstrual cycle (McNulty et al., 2020) may potentially modify these effects and this warrants investigation.

Most studies included here provided an acute 0.3 – 0.4 $g \cdot kg^{-1}$BM dose of SB in the 180 – 90 min prior to exercise, although two provided SB chronically (Delextrat et al., 2018; Durkalec-Michalski et al., 2020). These acute supplementation protocols are most commonly applied in the literature and also appear to be the most effective (Heibel et al., 2018). Overall, the effect on exercise is likely to be between small to medium in magnitude, which is consistent with what we currently know about the influence of SB in men. Based on these findings, we do not believe there is any evidence to support sex-specific SB dosing recommendations and that

current recommendations of 0.2 – 0.3 g·kg^{-1}BM of SB taken 60 – 180 min prior to high-intensity exercise (de Oliveira, Saunders, Yamaguchi, Swinton, & Artioli, 2020) appear appropriate for the female athlete.

This meta-analysis is somewhat limited by the low number of included articles and exercise outcomes, with only four studies reporting pre- to post-supplementation blood bicarbonate changes and twelve exercise outcomes. Nonetheless, evidence for large changes in blood bicarbonate was very strong and certainty in this outcome was high. Although certainty in exercise outcomes was only moderate, there was strong evidence that effects on exercise outcomes was greater than zero. This is further supported by individual study data, all of which suggests very small to large positive effects (Figure 2). Sodium bicarbonate supplementation has been shown to improve muscular endurance, but not muscular strength (Grgic et al., 2020). However, none of the included studies here measured muscular strength or endurance and, thus, any conclusions must be limited to these predominantly aerobic and anaerobic exercise protocols. Finally, these data are highly applicable for trained young women since most studies employed trained or elite female athletes with an average age across these studies of 19 – 26 years. The generalisability of these conclusions to middle-aged or elderly populations is currently less certain.

In conclusion, the scientific literature regarding the efficacy of SB on exercise performance is highly biased towards male participants. The limited data in women does provide evidence of a small to medium positive effect of supplementation on exercise performance.

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Table 1. Sodium bicarbonate studies with female participants analysed separately

Authors (Year)	Population	Supplementation	Study Design	Exercise Test	Familiarisation?
Bishop et al. (2004)	Recreational team-sport playing females (N=10)	0.3 $g \cdot kg^{-1}_{BM}$ 90 min prior to exercise in gelatine capsules. Placebo: NaCl (0.207 $g \cdot kg^{-1}_{BM}$)	Double-blind, Crossover	5 x 6 s repeated sprint cycling test	Yes
Bishop & Claudius (2005)	Team-sport athletes (N=7)	0.2 $g \cdot kg^{-1}_{BM}$ 110-90 min and 0.2 $g \cdot kg^{-1}_{BM}$ 50-20 min prior to exercise in gelatine capsules. Placebo: NaCl (2 x 0.138 $g \cdot kg^{-1}_{BM}$)	Double-blind, Crossover	Intermittent cycling sprint test 2 x 36 min of 4-s sprints, 100 s active recovery + 20 s recovery passive	Yes
Delextrat et al. (2018)	University basketball players (N=15)	0.4 $g \cdot kg^{-1}_{BM}$ per day for 3 days in gelatine capsules. Final ingestion the day before the test. Placebo: $CaCO_3$ (0.4 $g \cdot kg^{-1}_{BM}$)	Double-blind, Crossover	Basketball simulation test (repeated sprint and jump performance)	Yes
Edge et al. (2006)	Moderately trained students involved in club level sports (N=16)	0.2 $g \cdot kg^{-1}_{BM}$ 90 min and 0.2 $g \cdot kg^{-1}_{BM}$ 30 min prior to training throughout 8 weeks of training (3 x/week). Placebo: NaCl (2 x 0.1 $mg \cdot kg^{-1}_{BM}$)	Single-blind, Parallel groups	Cycling test at 100% of VO_{2peak} until exhaustion	Yes
Kozak-Collins et al. (1994)	Competitive cyclists (N=7)	0.3 $g \cdot kg^{-1}_{BM}$ 120 min prior to exercise in gelatine capsules Placebo: NaCl (0.207 $g \cdot kg^{-1}_{BM}$)	Double-blind, Crossover	1 min cycling at 95% VO_{2max} : 1 min recovery at 60 W (repeated until exhaustion)	No
Macutkiewicz & Sunderland (2018)	Elite hockey players (N=8)	0.2 $g \cdot kg^{-1}_{BM}$ 180 min and 0.1 $g \cdot kg^{-1}_{BM}$ 90 min prior to exercise in gelatine capsules. Placebo: Maltodextrin (0.2 $g \cdot kg^{-1}_{BM}$)	Single-blind, Crossover	Field Hockey Skill Tests Loughborough Intermittent Shuttle Test (4 sets)	Yes
Tan et al. (2010)	Elite water polo players (N=12)	0.3 $g \cdot kg^{-1}_{BM}$ 90 min prior to exercise in gelatine capsules. Placebo: Corn flour (undefined dose)	Double-blind, Crossover	Water polo match simulation test (59 min protocol with 56 x 10-m maximal-sprint swims)	Yes
McNaughton et al. (1997)	Physically active females (N=10)	0.3 $g \cdot kg^{-1}_{BM}$ 90 min prior to exercise in solution. Placebo: NaCl (0.207 $g \cdot kg^{-1}_{BM}$)	Double-blind, Crossover	Single maximal 1-min cycle effort	No
Tiryaki & Atterbom (1995)	Track athletes (N=11) and trained non-athletes (N=4)	0.3 $g \cdot kg^{-1}_{BM}$ 150 min prior to exercise in solution. Placebo: Sugarless Kool-Aid (undefined dose)	Double-blind, Crossover	600 m running test	Yes
Durkalec-Michalski et al. (2020)	High-level Polish freestyle wrestlers (N=18)	1-2 days: 25 $mg \cdot kg^{-1}$BM; 3-5 days: 50 $mg \cdot kg^{-1}_{BM}$; 6-7 days: 75 $mg \cdot kg^{-1}_{BM}$; 8-10 days: 100 $mg \cdot kg^{-1}_{BM}$; tablets. Placebo: NaCl + maltodextrin (undefined dose)	Double-blind, Parallel groups	2 x Wingate bouts and Dummy Throw Test	Yes
Voskamp et al. (2020)	Competitive cyclists (N=16)	0.3 $g \cdot kg^{-1}_{BM}$ 150 min prior to exercise in gelatine capsules	Double-blind, Crossover	2000 m cycling time-trial	Yes

		Placebo: sunflower, magnesium, amylum (undefined dose)			

BM = body mass