

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

3 Running head: Sodium bicarbonate and the female athlete

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30 **ABSTRACT**

31 Sodium bicarbonate (SB) is considered an effective ergogenic supplement for improving high-
32 intensity exercise capacity and performance, although recent data suggests that women may be
33 less amenable to its ergogenic effects than men. Currently, an apparent paucity of data on
34 women means no consensus exists on whether women benefit from SB supplementation. The
35 aim of the current study was to quantify the proportion of the published literature on SB
36 supplementation that includes women, and to synthesise the evidence **regarding its effects on**
37 **blood bicarbonate and exercise performance** in women by performing a systematic review and
38 meta-analysis. Electronic searches of the literature were undertaken using three databases
39 (MEDLINE, Embase, SPORTDiscus) to identify relevant articles. All meta-analyses were
40 performed within a Bayesian framework. A total of 149 SB articles were identified, 11 of which
41 contained individual group data for women. Results indicated a pooled blood bicarbonate
42 increase of 7.4 [95%CrI: 4.2 to 10.4 mmol·L⁻¹] following supplementation and a pooled
43 standardised exercise effect size of 0.37 [95%CrI: -0.06 to 0.92]. The SB literature is skewed,
44 with only 20% (30 studies) of studies employing female participants, of which only 11 studies
45 (7.4%) provided group analyses exclusively in women. Despite the small amount of available
46 data, results are consistent in showing that SB supplementation in women leads to large
47 changes in blood bicarbonate and that there is strong evidence for a positive ergogenic effect
48 on exercise performance that is likely to be small to medium in magnitude.

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

51

52 **Introduction**

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

63
64 A number of factors may moderate the effect of SB supplementation on exercise outcomes,
65 including supplement dose, timing and training status ([Heibel, Perim, Oliveira, McNaughton,](#)
66 [& Saunders, 2018](#)). However, little is currently known about whether sex influences the
67 response to SB supplementation, although this seems plausible given evidence that women
68 have a lower tolerance for high-intensity exercise performance than men ([Russ, Lanza,](#)
69 [Rothman, & Kent-Braun, 2005](#)) likely due in part to less overall muscle mass ([Hegge et al.,](#)
70 [2016](#); [Janssen, Heymsfield, Wang, & Ross, 2000](#)) and lower type II muscle fibre distribution
71 ([Porter, Stuart, Boij, & Lexell, 2002](#); [Simoneau & Bouchard, 1989](#)). Findings demonstrate
72 women also have a lower overall capacity for glycolysis due to lower glycolytic enzyme
73 activity ([Green, Fraser, & Ranney, 1984](#)), leading to less acidosis ([Russ, Lanza, Rothman, &](#)
74 [Kent-Braun, 2005](#)). Theoretically, this could mean that women may have a smaller response to
75 a buffering agent intended to improve high-intensity exercise performance. A recent study
76 supports this theory showing an improvement in Wingate and wrestling specific performance

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

92 **Methods**

93 *Study Eligibility*

94 The protocol for this study was designed in accordance with Preferred Reporting Items for
95 Systematic Reviews and Meta-Analyses (PRISMA) guidelines ([Moher, Liberati, Tetzlaff,
96 Altman, & Group, 2009](#)) and the research question determined with reference to PICOS
97 (Population, Intervention, Comparator, Outcomes and Study Design). The study was not pre-
98 registered. Initially, the literature was screened to identify all SB supplementation studies with
99 both male and female *populations*. This broader screening strategy was used to identify the
100 proportion of the total evidence base that employed female participants. The data extraction
101 and meta-analysis was subsequently based only on those studies that included a group
102 consisting of women only. The *intervention* must have employed an acute (<1 day) or chronic
103 (>1 day) supplementation protocol with SB prior to performing an exercise test. The
104 *comparator* for the meta-analysis determined that only **single or double-blinded**, placebo-
105 controlled studies were included. Studies that reported on *outcomes* based on exercise
106 performance and capacity **tests** were considered for inclusion ([Saunders et al., 2017](#)) and *study*
107 *design* allowed both crossover and parallel group designs. Only peer-reviewed, English
108 language, original human studies were included.

109

110 *Search Strategy*

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

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

120

121 *Certainty in cumulative outcomes*

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

135

136 *Data Extraction*

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

142 [Claudius, 2005](#); [Bishop, Edge, Davis, & Goodman, 2004](#); [Kozak-Collins, Burke, & Schoene,](#)
143 [1994](#); [Tan et al., 2010](#)) data were extracted from figures using digitizing software (DigitizeIt;
144 [Rakap, Rakap, Evran, & Cig, 2016](#)). To avoid duplication bias, when an exercise protocol
145 resulted in multiples outcome measures of the same exercise test, a solitary outcome measure
146 was extracted based upon the following hierarchy: i) total work done; ii) mean output
147 throughout the test (*i.e.*, mean power output; mean velocity; mean height); time-to-completion
148 (performance test)/time to exhaustion (capacity test).

149

150 *Statistical Analysis*

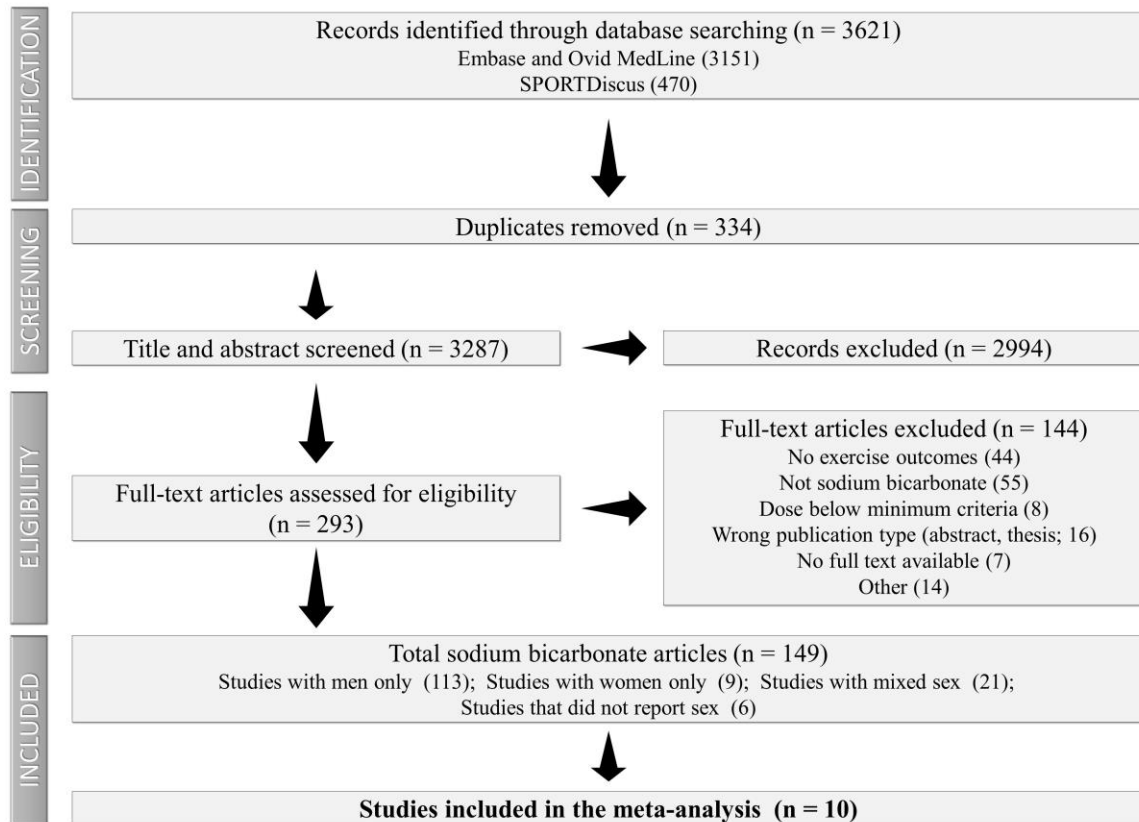
151 All meta-analyses (performed by PAS) were conducted within a Bayesian framework to
152 provide a more flexible modelling approach and enable results to be interpreted intuitively
153 through reporting of subjective probabilities ([Kruschke & Liddell, 2018](#)). The first meta-
154 analysis pooled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

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

180 **Results**

181 *Study search*

182 A total of 149 SB articles were identified following the search and filter (Figure 1), of which
183 113 (76%) recruited men only and 9 (6%) women only. A total of 21 studies (14%) recruited
184 both **men and women**, 2 of which separated according to sex for analyses, and 19 of which did
185 not, grouping data for both men and women. Six (4%) studies did not specify the sex of their
186 participants. This resulted in a total of 1175 men and 134 women analysed separately. Studies
187 that analysed men and women together comprised 273 individuals, of which 195 were men and
188 78 were women. Of the 30 studies including women, only one reported information relating to
189 the menstrual cycle or contraceptive use of the participants ([Macutkiewicz & Sunderland,](#)
190 [2018](#)), with the same study the only to control for menstrual cycle phase during the testing
191 period. Only 11 studies with standalone female groups were taken forward to the meta-analysis.



192

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

195

196 *Meta-analysis*

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

202

203 *Blood bicarbonate*

204 Blood bicarbonate data were available from four studies ([Bishop & Claudius, 2005](#); [Bishop,](#)
 205 [Edge, & Goodman, 2004](#); [McNaughton et al., 1997](#); [Tan et al., 2010](#)) totalling 39 participants.
 206 Results indicated a pooled blood bicarbonate increase of 7.4 [95%CrI: 4.2 to 10.4 mmol·L⁻¹;
 207 $P(\text{Increase} > 5) = 0.937$] following supplementation. The between study variance was 3.7

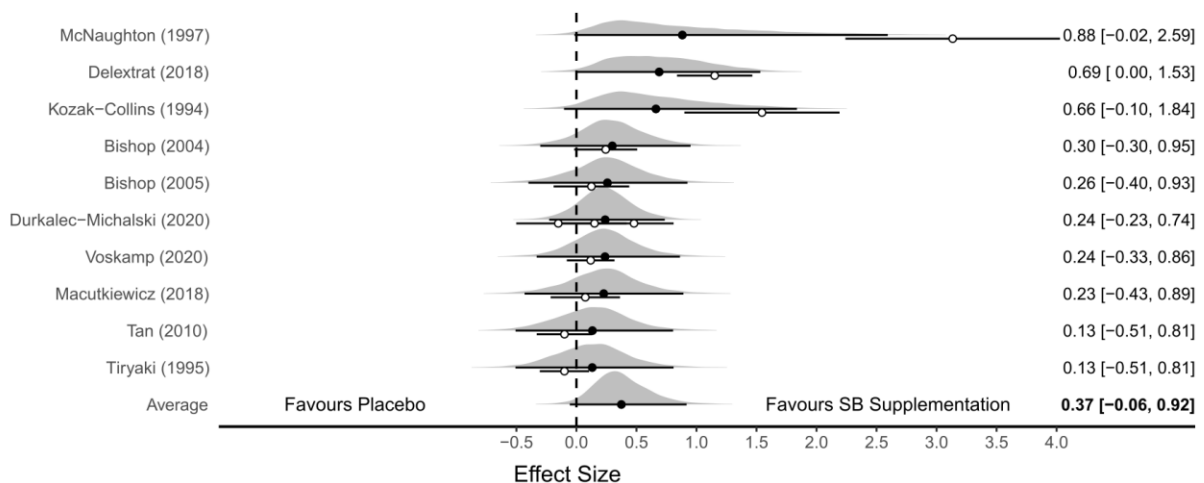
208 [95%CrI: 2.2 to 7.8 mmol·L⁻¹]. Median values and probabilities remained unchanged in the
 209 sensitivity analysis conducted with all data points and robust variance estimation.

210

211 *Exercise data*

212 Twelve exercise outcomes were obtained from ten studies ([Bishop & Claudius, 2005](#); [Bishop,](#)
 213 [Edge, Davis, et al., 2004](#); [Delextrat et al., 2018](#); [Durkalec-Michalski et al., 2020](#); [Macutkiewicz](#)
 214 [& Sunderland, 2018](#); [McNaughton et al., 1997](#); [Tan et al., 2010](#); [Tiryaki & Atterbom, 1995](#);
 215 [Voskamp et al., 2020](#)) totalling 109 participants. Results indicated a pooled standardised effect
 216 size of 0.37 [95%CrI: -0.06 to 0.92; $P(\text{Increase} > 0) = 0.962$; $P(\text{Increase} > 0.2) = 0.784$;
 217 $P(\text{Increase} > 0.5) = 0.263$; Figure 2] and a between study variance of 0.38 [95%CrI: 0.02 to
 218 1.2]. Sensitivity analysis with the robust t-distribution to account for the small number of data
 219 points and existence of some large individual effects sizes estimated a slightly smaller pooled
 220 effect size 0.29 [95%CrI: -0.07 to 0.84; $P(\text{Increase} > 0) = 0.949$; $P(\text{Increase} > 0.2) = 0.689$;
 221 $P(\text{Increase} > 0.5) = 0.191$]. Meta-regression provided no substantive evidence of a moderating
 222 effect of exercise duration, with the estimated difference between short (<30 s; 5 studies, n=54)
 223 and longer duration (≥ 30 s; 6 studies, n=71) exercise tests estimated to be 0.02 [95%CrI: -0.52
 224 to 0.55; $P(\text{Difference} > 0) = 0.526$].

225



226

227 **Figure 2. Bayesian Forest Plot of effect sizes for sodium bicarbonate (SB) supplementation on exercise**
228 **performance. Distributions represent “shrunk estimates” based on all effects size obtained from the**
229 **study, the random effects model fitted and borrowed information across studies to reduce uncertainty.**
230 **Black circles and connected intervals represent the median value and 95% credible intervals for the**
231 **shrunk estimates. White circles and intervals represent the raw estimates and sampling variance**
232 **calculated directly from study data.**
233

234 *Certainty in cumulative outcomes*

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

Study	Risk of bias domains					Overall
	D1	D2	D3	D4	D5	
Bishop et al. (2004)	+	+	+	+	-	-
Bishop & Claudius (2005)	+	+	+	+	-	-
Delextrat et al. (2018)	+	+	+	+	-	-
Durkalec-Michalski et al. (2020)	+	+	+	+	-	-
Kozak-Collins et al. (1994)	+	+	+	-	-	-
Macutkiewicz & Sunderland (2018)	+	+	+	-	-	-
McNaughton et al. (1997)	+	+	+	-	-	-
Tan et al. (2010)	+	+	+	+	-	-
Tiryaki & Atterbom (1995)	+	+	+	+	-	-
Voskamp et al. (2020)	+	+	+	+	-	-

Domains:
D1: Bias arising from the randomization process.
D2: Bias due to deviations from intended intervention.
D3: Bias due to missing outcome data.
D4: Bias in measurement of the outcome.
D5: Bias in selection of the reported result.

Judgement
- Some concerns
+ Low

245 **Figure 3. Risk of bias assessment of the ten studies included in the meta-analysis. (Plot was created using**
246 **robvis (McGuinness & Higgins, 2020) and are in a colourblind-friendly colour scheme).**
247

248
249
250 Both blood and exercise outcomes were downgraded for imprecision due to low numbers of
251 outcome measures (four for blood, 12 for exercise). Consistent blood and exercise effects
252 meant no measure was downgraded for inconsistency. Almost all studies were performed in
253 young, trained women with commonly employed dosing strategies and, thus, deemed to have
254 direct, real-life applicability for the female athlete and were not downgraded for indirectness.
255 Nonetheless, downgrading of certainty based on indirectness may be advisable for those
256 interested in other populations (e.g., middle-aged, or elderly populations) or exercise outcomes
257 (e.g., resistance/strength exercise). Publication bias was not explored due to limited data and
258 consistency across study sample sizes, meaning no outcome was downgraded for this domain
259 but future meta-analyses with a larger number of studies will allow this to be ascertained. Blood
260 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).

266 **Discussion**

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

276

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

290

291 The recent data of Durkalec-Michalski et al. ([2020](#)) showed that SB supplementation improved
292 wrestling specific performance in men, but not women. The authors speculated that
293 physiological factors that might explain these divergent responses include differences in
294 muscle fibre type and anaerobic capacity. Women typically have less overall muscle mass
295 ([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](#);
297 [Tarnopolsky, 2000](#)), meaning they might be less susceptible to performance affecting decreases
298 in muscle pH and, thus, also less susceptible to performance improvements with increased
299 buffering capacity. The results of this study contrast with this hypothesis and the results of
300 Durkalec-Michalski et al. ([2020](#)) and suggest that women do benefit from SB supplementation.
301 This discrepancy might be due to a low sample size in Durkalec-Michalski et al. ([2020](#)) which
302 was potentially unable to detect small differences in performance of these exercise tests. The
303 number of women in their study was almost half that of men (18 vs. 33), and although women
304 showed no improvements while men did, performance changes for women appear similar to
305 those of men (Figure 3 of the original article).

306

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

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

333

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

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

344

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

359

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

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Authors (Year)	Population	Supplementation	Study Design	Exercise Test	Familiarisation?
Bishop et al. (2004)	Recreational team-sport playing females (N=10)	0.3 g·kg ⁻¹ _{BM} 90 min prior to exercise in gelatine capsules. Placebo: NaCl (0.207 g·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·kg ⁻¹ _{BM} 110-90 min and 0.2 g·kg ⁻¹ _{BM} 50-20 min prior to exercise in gelatine capsules. Placebo: NaCl (2 x 0.138 g·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·kg ⁻¹ _{BM} per day for 3 days in gelatine capsules. Final ingestion the day before the test. Placebo: CaCO ₃ (0.4 g·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·kg ⁻¹ _{BM} 90 min and 0.2 g·kg ⁻¹ _{BM} 30 min prior to training throughout 8 weeks of training (3 x/week). Placebo: NaCl (2 x 0.1 mg·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·kg ⁻¹ _{BM} 120 min prior to exercise in gelatine capsules Placebo: NaCl (0.207 g·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·kg ⁻¹ _{BM} 180 min and 0.1 g·kg ⁻¹ _{BM} 90 min prior to exercise in gelatine capsules. Placebo: Maltodextrin (0.2 g·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·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·kg ⁻¹ _{BM} 90 min prior to exercise in solution. Placebo: NaCl (0.207 g·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·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·kg ⁻¹ _{BM} ; 3-5 days: 50 mg·kg ⁻¹ _{BM} ; 6-7 days: 75 mg·kg ⁻¹ _{BM} ; 8-10 days: 100 mg·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·kg ⁻¹ _{BM} 150 min prior to exercise in gelatine capsules Placebo: sunflower, magnesium, amyllum (undefined dose)	Double-blind, Crossover	2000 m cycling time-trial	Yes

