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1 **Warm-up intensity does not affect the ergogenic effect of sodium**
2 **bicarbonate in adult men.**

3 **AUTHORS:** Rebecca Louise Jones^{1,7*}, Trent Stellingwerff^{2,3}, Paul Swinton⁴, Guilherme
4 Giannini Artioli⁵, Bryan Saunders^{5,6} and Craig Sale⁷.

5 **AFFILIATIONS:**

6 ¹Institute for Sport and Physical Activity Research, School of Sport Science and Physical
7 Activity, University of Bedfordshire, Bedford, UK.

8 ²Canadian Sport Institute–Pacific, Victoria, Canada.

9 ³Exercise Science, Physical & Health Education, University of Victoria British Columbia,
10 Canada.

11

12 ⁴School of Health Science, Faculty of Health and Social Care Building, Robert Gordon
13 University, Aberdeen, UK.

14 ⁵Applied Physiology and Nutrition Research Group, School of Physical Education and Sport;
15 Rheumatology Division; Faculdade de Medicina FMUSP, Universidade de Sao Paulo, Sao
16 Paulo, SP, BR, University of São Paulo, SP, BR.

17 ⁶Institute of Orthopaedics and Traumatology, Faculty of Medicine FMUSP, University of São
18 Paulo, SP, BR.

19 ⁷Musculoskeletal Physiology Research Group, Sport, Health and Performance Enhancement
20 (SHAPE) Research Centre, School of Science & Technology, Nottingham Trent University,
21 UK.

22

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30 **Corresponding author:** Dr Rebecca Louise Jones, School of Sport Science and Physical
31 Activity, University of Bedfordshire, Polhill Avenue, Bedford, MK41 9EA. Tel: 01234
32 793080; Mob: 07527722167. Email: Rebecca.Jones@beds.ac.uk

33 **ABSTRACT**

34 This study determined the influence of a high (HI) vs. low-intensity (LI) cycling warm-up on
35 blood acid-base responses and exercise capacity following ingestion of sodium bicarbonate
36 (SB; 0.3 g·kg⁻¹ body-mass (BM)) or a placebo (PLA; maltodextrin) 3-hours prior to warm-up.
37 Twelve men (21±2 years, 79.2±3.6 kg BM, maximum power output (W_{max}) 318±36 W)
38 completed a familiarisation and four double-blind trials completed in a counterbalanced order:
39 HI warm-up with SB (HISB); HI warm-up with PLA (HIPLA); LI warm-up with SB (LISB);
40 and LI warm-up with PLA (LIPLA). LI warm-up was 15-minutes at 60% W_{max} , while the HI
41 warm-up (typical of elites) featured LI followed by 2 x 30-sec (3-minute break) at W_{max} ,
42 finishing 30-minute prior to a cycling capacity test at 110% W_{max} (CCT_{110%}). Blood bicarbonate
43 and lactate were measured throughout. SB supplementation increased blood bicarbonate (+6.4
44 [95%CI: 5.7 to 7.1 mmol·L⁻¹]) prior to greater reductions with high intensity warm-up (-3.8
45 [95%CI: -5.8 to -1.8 mmol·L⁻¹]). However, during the 30-minute recovery, blood bicarbonate
46 rebounded and increased in all conditions, with concentrations ~5.3mmol·L⁻¹ greater with SB
47 supplementation (P<0.001). Blood bicarbonate significantly declined during the CCT_{110%} with
48 greater reductions following SB supplementation (-2.4 [95%CI: -3.8 to -0.90 mmol·L⁻¹]).
49 Aligned with these results, SB supplementation increased total work done during the CCT_{110%}
50 (+8.5 [95%CI: 3.6 to 13.4 kJ], ~19% increase) with no significant main effect of warm-up
51 intensity (+0.0 [95%CI: -5.0 to 5.0 kJ]). Collectively, the results demonstrate that SB
52 supplementation can improve HI cycling capacity irrespective of prior warm-up intensity,
53 likely due to blood alkalosis.

54 **KEY WORDS:** Supplementation, high-intensity, low-intensity, buffering

55 INTRODUCTION

56 Muscle acidosis caused by the accumulation of intramuscular hydrogen cations (H^+) can hinder
57 enzymatic energy production and contractility of the muscle (Jubrias, Crowther, Shankland,
58 Gronka, & Conley, 2003; Woodward & Debold, 2018), contributing to the fatigue process
59 during exercise (Fitts, 2016). Sodium bicarbonate (SB) ingestion increases the concentration
60 of blood bicarbonate leading to a greater efflux of H^+ and lactate anions out of the skeletal
61 muscle which can be beneficial to high-intensity (HI; ~2 to 10-minutes) performance (Carr,
62 Hopkins, & Gore, 2011; Christensen, Shirai, Ritz, & Nordsborg, 2017). Ingestion of SB prior
63 to HI exercise has a moderate positive effect size on exercise outcomes (Christensen et al.,
64 2017; Matson & Tran, 1993; Peart, Siegler, & Vince, 2012), with larger effect sizes in non-
65 trained individuals compared to trained athletes (Peart et al., 2012). Accordingly, SB is one of
66 few performance-enhancing supplements with ample support for performance efficacy
67 (Maughan et al., 2018).

68

69 Warming-up prior to a specific exercise bout is a commonly employed practice and is
70 considered essential by coaches and athletes to achieve optimal performance. The aim of a
71 warm-up is to elicit various physiological effects, such as increased body and muscle
72 temperature, metabolic and neural stimulation, that can enhance muscle function and
73 subsequent performance (McGowan, Pyne, Thompson, & Rattray, 2015). Pre-exercise HI
74 warm-ups, can improve subsequent HI exercise tolerance due to a speeding of VO_2 kinetics
75 and a greater oxidative-energy contribution to subsequent exercise (Burnley, Doust, & Jones,
76 2005; Ingham, Fudge, Pringle, & Jones, 2013). The beneficial effect of priming exercise has a
77 “Goldilocks zone”, and is apparent only when the warm-up intensity leads to blood lactate
78 concentrations of $3\text{-}5\text{mmol}\cdot\text{L}^{-1}$ (Bailey, Vanhatalo, Wilkerson, Dimenna, & Jones, 2009;

79 Ingham et al., 2013) with a sufficient recovery period (>9-minute; (Bailey et al., 2009). Warm-
80 up intensities that lead to higher and lower increases in blood lactate, and an insufficient
81 recovery period, do not enhance and may even impair subsequent (Bailey et al., 2009; Burnley,
82 Doust, Carter, & Jones, 2001). HI warm-ups increase glycolytic enzyme and transporter
83 activation, as well as biomechanical and psychological stimuli, which all can positively prime
84 HI performance. The increased muscle lactate production from the HI warm-up, however,
85 needs adequate time to be removed from the muscle. Since lactate/proton co-transport is the
86 predominant lactate transport system in muscle (Juel, 1997), H⁺ will also enter circulation.
87 Thus, it is interesting to speculate how much of the pre-exercise bicarbonate concentration is
88 affected by warm-up intensity that precedes it, and if any differences are altered due to prior
89 SB supplementation.

90

91 Despite the existing evidence base supporting performance enhancing effect of SB, many
92 studies have not considered the impact of the warm-up prior to exercise. Many SB studies have
93 employed LI warm-ups with short recovery periods prior to the main exercise task (Froio de
94 Araujo Dias et al., 2015; Saunders, Sale, Harris, & Sunderland, 2014), which limits the
95 extrapolation of results to the real-world setting, since athletes involved in HI competitions
96 would likely employ a HI warm-up (Ingham et al., 2013). It might be suggested that the
97 recovery kinetics of bicarbonate following a warm-up and the time taken between warm-up
98 and the subsequent bout of exercise could be important for performance. Despite this, many
99 studies only allow relative short periods or recovery between a warm-up and subsequent
100 exercise. However, it is not uncommon for elite athletes, and required within the rules of many
101 sports (competition “check-in” time) to finish warm-ups 20-40-minutes prior to competition,
102 allowing for greater recovery (Ingham et al., 2013). It is unknown if SB supplementation prior

103 to a HI or LI warm-up would be similarly effective due to buffering requirements during the
104 warm-up itself.

105

106 Although HI athletes will regularly consume SB and perform HI warm-ups, no evidence exists
107 to determine the impact of warm-up intensity on blood acid-base responses and the influence
108 of this upon subsequent HI cycling capacity and performance. Therefore, we examined the
109 effects of warm-up intensity and SB supplementation upon cycling capacity and blood acid-
110 base analyte responses. Our hypothesis is that SB supplementation would enhance exercise
111 performance regardless of warm-up intensity, although the HI warm-up condition would result
112 in greater enhancement, compared to the LI condition.

113 **METHODS**

114 **Participants**

115 Fourteen physically active men volunteered for this double-blind, order-balanced, crossover
116 study. Two participants withdrew, one due to gastrointestinal (GI) distress experienced during
117 one of the trials, and one due to an injury not associated with the protocol, therefore twelve
118 men (age, 21 ± 2 years; height, 1.82 ± 0.06 m; body mass (BM), 79.2 ± 3.6 kg) completed all
119 experimental sessions. Participants provided written informed consent and completed a health
120 screen questionnaire prior to taking part in the study at Nottingham Trent University, which
121 was approved by Nottingham Trent University Ethical Advisory Committee [#364] in
122 accordance with the Declaration of Helsinki. Participants had not ingested any nutritional
123 supplement or suffered from any GI problems in the previous six months.

124

125 **Protocol and measurements**

126 The current investigation was conducted as part of a wider research project, with all participants
127 completing a total of seven separate laboratory sessions performed in a counterbalanced order.
128 The current investigation will report data from five occasions. The first visit determined
129 individual's height (m) and body mass (kg) followed by an incremental cycling test to
130 determine maximum power output (W_{\max}) and a familiarisation of the main exercise protocol.
131 The incremental exercise test was performed on a cycle ergometer (Lode Excalibur, Groningen,
132 Netherlands) and began at a starting power output of 150 W, exercise intensity increasing by 6
133 W every 15 s (ramp rate of $24 \text{ W} \cdot \text{min}^{-1}$) until volitional exhaustion according to Saunders et
134 al. (2013). Participants completed each of the four main trials at the same time of day, having
135 replicated dietary intake, abstained from alcohol and strenuous exercise for the 24h prior and
136 from caffeine on test days. Experimental sessions were separated by a minimum of five days,

137 with an average of seven days between visits. Resting fingertip blood samples were obtained
138 prior to the supervised consumption of either $0.3\text{g}\cdot\text{kg}^{-1}\text{BM}$ of SB (Intralabs, UK) or a placebo
139 (PLA; Maltodextrin; MyProtein, UK) provided in identical clear gelatine capsules and ingested
140 with 500 ml of water (Figure 1). Supplements were prepared and allocated by an individual not
141 involved in the study. The allocation code was retained by this individual until the end of
142 statistical analysis at which point the allocation code was released to the experimenters. As
143 such, neither experimenter nor participant was aware of what supplement was being consumed
144 on any given occasion. Supplements were independently tested by HFL Sports Science, UK
145 (ISO 17025). Following ingestion, participants remained rested for a three-hour period during
146 which no food was consumed. The supplementation timing was employed so that the onset of
147 exercise occurred at a moment at which peak gastrointestinal discomfort would likely have
148 passed, but blood bicarbonate would still be increased above $+6\text{mmol}\cdot\text{L}^{-1}$ (Jones et al., 2016).
149 Six out of 12 participants were able to correctly guess their supplement during the first and
150 second trials, whereas nine out of 12 and eight out of 12 correctly guessed their supplement in
151 the third and fourth trials. There were no significant differences in the correct guessing rate
152 between trials for all six trials combined (Fisher Exact Test: $P=0.39$).

153

154 A fingertip blood sample was obtained immediately-prior to a LI (15-minutes of cycling at
155 $60\% W_{\text{max}}$ ($191\pm 21\text{W}$)) or HI (5-minutes at $60\% W_{\text{max}}$, 5-minutes at $70\% W_{\text{max}}$ ($223\pm 25\text{W}$), 5-
156 minutes at $80\% W_{\text{max}}$ ($255\pm 29\text{W}$), 30 s at W_{max} ($318\pm 36\text{W}$), followed by a 3-minute break and
157 another 30 s at W_{max}) warm-up. This resulted in four different intervention conditions: HI
158 warm-up and SB (HISB); HI warm-up and PLA (HIPLA); LI warm-up and SB (LISB); and LI
159 warm-up and PLA (LIPLA). The HI warm-up was based on a typical elite track-cycling
160 protocol, finishing 30-minutes prior to competition (*personal observations/discussions in elite*
161 *sport via T. Stellingwerff*). Participants remained seated for 30-minutes following completion

162 of the warm-up, with fingertip blood samples taken at 10-minute intervals. Participants then
163 completed a cycling capacity test to exhaustion at 110% W_{\max} ($CCT_{110\%}$; $350\pm 39W$) (Saunders,
164 Sale, Harris, Morris, & Sunderland, 2013). A capacity test was chosen here due to the high-
165 intensity nature of the activity and since many sports require athletes to exert themselves
166 maximally to the point of exhaustion to maintain race pace (e.g., athletics) or for the benefit of
167 the team (e.g., domestiques in cycling). The position on the cycle ergometer (Lode Excalibur
168 Sport) was determined in the familiarisation session and maintained for all subsequent trials.
169 Due to the intense nature of the exercise test, the first 30 s of the test was incremented (15 s at
170 80% W_{\max} and 15 s at 95% W_{\max} ($302\pm 34W$). Total work done (TWD; in kJ) and time-to-
171 exhaustion (TTE; in s) were recorded as the outcome measure for all cycling capacity tests.
172 Fingertip capillary blood samples were taken immediately and 5-minutes following completion
173 of the $CCT_{110\%}$. All blood samples (80 μL) were collected in heparin-coated clinitubes and
174 immediately analysed for lactate and PCO_2 concentration (Radiometer ABL 900, Radiometer
175 Ltd, UK), with bicarbonate and base excess calculated using the Henderson-Hasselbalch
176 equation.

177

178 **Statistical Analysis**

179 An *a-priori* power calculation indicated that a minimum of 12 participants were required to
180 detect power at >95% ($\alpha=0.01$; within-subject effect in a repeated measures ANOVA with 1
181 group and 6 measurements) using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007).
182 Calculations were based on TWD from Peart et al., (2012) (Cohen's *d*: 0.6). Data obtained
183 from blood samples were analysed sequentially across the distinct measurement periods to
184 better describe the effects of warmup on blood bicarbonate and lactate kinetics. The
185 measurement periods were separated into four distinct periods for analysis: 1)

186 Supplementation: Baseline to warm-up onset; 2) Warm-up: Warm-up onset to post-warm-up;
187 3) Recovery: post-warm-up to exercise onset; 4) Exercise: Exercise onset to recovery post
188 exercise. Mixed effects regression models were used to assess main and interaction effects of
189 supplementation (PLA vs SB) and warm-up (LI vs HI) whilst participant ID's were included
190 as random effects to account for the repeated measures nature of the data (Mirman, 2014). The
191 supplementation, warm-up and exercise phases included two sequential measurement points
192 and were, therefore could only be modelled by a straight line. In contrast, the recovery period
193 comprised three sequential data points and was modelled with both linear and quadratic
194 regression lines. Standard errors and P values for regression coefficients were obtained with
195 the lmerTest library in R using Satterthwaite's approximation for degrees of freedom
196 (Kuznetsova, Brockhoff, & Christensen, 2017). To test whether a linear or quadratic model
197 best fit the data for the recovery period, a likelihood ratio test with appropriate chi-squared
198 asymptotic reference distribution was used (Mirman, 2014).

199 Proportion of response was used to interpret the “practical significance” of supplementation by
200 estimating the chance a new person from the population of interest would experience a
201 substantive improvement in performance as a direct effect of supplementation (Atkinson,
202 Williamson, & Batterham, 2019). TWD and TTE were used as measures of performance, with
203 response defined as improvement beyond the smallest worthwhile change (SWC: calculated as
204 $0.2 \times$ the group standard deviation during the PLA session (Paton & Hopkins, 2006)).
205 Assessment of response was made using recommended group-based data practices (Atkinson,
206 Williamson, & Batterham, 2019) and not investigation of specific individuals in the samples.
207 Therefore, the spreadsheet of Swinton et al., (2018) was used to calculate uncertainty in the
208 proportion of response estimates.

209 RESULTS

210 *Exercise capacity*

211 Significant main effects were identified for SB supplementation (Figure 2) resulting in
212 increases in TWD (8.5 [95%CI: 3.6 to 13.4 kJ], $P=0.002$) and TTE (24.6 [95%CI: 10.4 to 38.8
213 s], $P=0.002$). No significant main effects were identified for warm-up intensity (TWD: 0.0
214 [95%CI: -5.0 to 5.0 kJ], $P=0.999$; TTE (-0.42 [95%CI: -14.6 to 13.8 s], $P=0.954$) or interaction
215 between intensity and supplementation (TWD: -1.8 [95%CI: -8.7 to 5.2 kJ], $P=0.627$; TTE (-
216 4.7 [95%CI: -24.8 to 15.4 s], $P=0.652$)). The smallest worthwhile change and proportion of
217 response were estimated as 2.2 kJ and 89.2% (95%CI: 80.7–100%) for TWD and 5.5 s and
218 91.5% (95%CI: 82.1–100%) for TTE.

219

220 *Bicarbonate*

221 A significant main effect was obtained for SB supplementation demonstrating increased blood
222 bicarbonate concentrations from baseline to pre-warm-up (6.4 [95%CI: 5.7 to 7.1 $\text{mmol}\cdot\text{L}^{-1}$],
223 $P<0.001$) with no significant main effect obtained for PLA (0.0 [95%CI: -5.6 to 5.6 $\text{mmol}\cdot\text{L}^{-1}$],
224 $P=0.985$; Figure 3). Blood bicarbonate decreased in all conditions following the warm-up
225 period (LISB: -10.0 ± 2.7 $\text{mmol}\cdot\text{L}^{-1}$; LIPLA: -7.0 ± 2.5 $\text{mmol}\cdot\text{L}^{-1}$; HISB: -14.5 ± 4.6 $\text{mmol}\cdot\text{L}^{-1}$;
226 HIPLA: -10.9 ± 1.9 $\text{mmol}\cdot\text{L}^{-1}$; $P<0.001$) with significant main effects obtained for both SB
227 supplementation (-3.7 [95%CI: -5.7 to -1.7 $\text{mmol}\cdot\text{L}^{-1}$], $P<0.001$) and warm-up intensity (-3.8
228 [95%CI: -5.8 to -1.8 $\text{mmol}\cdot\text{L}^{-1}$], $P<0.001$). These effects did not, however, fully offset the
229 initial increase in blood bicarbonate with supplementation (Figure 3).

230

231 During the 30-minute recovery period different rates and profiles of blood bicarbonate
232 formation “rebound” were identified (Figure 3). The greatest rate of increase was in HISB
233 which was shown to be linear ($P=0.630$), whereas formation during all other conditions were
234 non-linear ($P\leq 0.024$) with rates slowing as time progressed. During the rebound period, blood
235 bicarbonate increased $+7.8\pm 1.5$ mmol·L⁻¹ in LISB, $+5.8\pm 1.7$ mmol·L⁻¹ in LIPLA, $+11.2\pm 4.1$
236 mmol·L⁻¹ in HISB and $+8.2\pm 1.6$ mmol·L⁻¹ in HIPLA. At the end of the recovery period, no
237 significant main effect of warm-up intensity was obtained (1.0 [95%CI: -0.41 to 2.4 mmol·L⁻¹],
238 $P=0.160$), whereas on average blood bicarbonate was estimated to be 5.3 mmol·L⁻¹ greater
239 (5.3 [95%CI: 3.9 to 6.7 mmol·L⁻¹], $P<0.001$) with supplementation (Figure 3: Post recovery).

240 During the CCT_{110%} a significant main effect was obtained for SB supplementation
241 demonstrating greater decreases in blood bicarbonate concentrations (-2.4 [95%CI: -3.8 to $-$
242 0.90 mmol·L⁻¹], $P=0.003$). No significant main effects were identified for warm-up intensity
243 (1.0 [95%CI: -0.5 to 2.5 mmol·L⁻¹], $P=0.188$) or interaction between intensity and
244 supplementation (0.5 [95%CI: -1.7 to 2.8 mmol·L⁻¹], $P=0.637$). However, despite these greater
245 decreases, at the end of the CCT_{110%} absolute blood bicarbonate concentrations remained
246 higher with SB (2.9 [95%CI: 1.8 to 4.0 mmol·L⁻¹], $P<0.001$), with no significant main effect
247 of warm-up intensity (0.0 [95%CI: -1.1 to 1.1 mmol·L⁻¹], $P=0.971$). No main effects of warm-
248 up intensity or supplementation ($P\geq 0.095$) were obtained for changes in blood bicarbonate
249 concentrations during the 5-minute recovery following the CCT_{110%}.

250

251 *Lactate*

252 Blood lactate concentrations increased in all conditions following the warm-up (LISB:
253 $+10.1\pm 3.4$ mmol·L⁻¹; LIPLA: $+8.1\pm 3.5$ mmol·L⁻¹; HISB: $+16.0\pm 6.0$ mmol·L⁻¹; HIPLA:
254 13.1 ± 3.6 mmol·L⁻¹, Figure 4: Post WU) with significant main effects obtained for both SB

255 supplementation (3.2 [95%CI: 0.5 to 5.8 mmol·L⁻¹], P=0.022]) and warm-up intensity (4.7
256 [95%CI: 2.2 to 7.2 mmol·L⁻¹], P<0.001).

257 During the 30-minute recovery period, different rates and profiles were identified (Figure 4).
258 The greatest rate of removal was in HISB which was linear (P=0.080), whereas blood lactate
259 removal during all other conditions were non-linear (P<0.001), rates slowed as time
260 progressed. At the end of recovery period a significant interaction effect was obtained (1.7
261 [95%CI: 0.2 to 3.3 mmol·L⁻¹], P=0.031) as well as significant main effects of SB
262 supplementation (2.1 [95%CI: 1.1 to 3.1 mmol·L⁻¹], P<0.001) and warm-up intensity (1.3
263 [95%CI: 0.33 to 2.3 mmol·L⁻¹], P=0.014). As a result, lactate concentrations were substantively
264 higher in the HISB condition compared to all other conditions (LISB: 3.0±1.3 mmol·L⁻¹; HISB:
265 6.1±2.6 mmol·L⁻¹; LIPLA: 2.6±1.0 mmol·L⁻¹; HIPLA: 4.1±2.1 mmol·L⁻¹; Figure 4: Post
266 Recovery).

267 Blood lactate concentrations increased substantively during the CCT_{110%} (Figure 4: CCT_{110%})
268 but no significant interaction (1.7 [95%CI: -1.1 to 4.5 mmol·L⁻¹], P=0.229) or main effects (SB
269 supplementation: 0.6 [95%CI: -1.2 to 2.5 mmol·L⁻¹], P=0.509; warm-up intensity: 0.6 [95%CI:
270 -1.2 to 2.5 mmol·L⁻¹], P=0.509) were obtained. Post CCT_{110%} blood lactate concentrations
271 remained on average 2.7 mmol·L⁻¹ higher post CCT_{110%} with SB supplementation (2.7 [95%CI:
272 1.0 to 4.5 mmol·L⁻¹], P=0.004) with no significant main effect of warm-up intensity (-0.4
273 [95%CI: -2.3 to 1.6 mmol·L⁻¹], P=0.675).

274

275 **DISCUSSION**

276 Sodium bicarbonate ingestion significantly increased blood bicarbonate concentrations from
277 baseline, while blood bicarbonate reduced and lactate increased following the warm-up; blood
278 responses occurred to a greater degree in the HI warm-up condition compared to the LI, and in
279 SB compared to PLA (Figure 3 and 4). Blood bicarbonate was higher, and lactate lower,
280 following 30-minute recovery in SB than PLA, with SB ingestion resulting in improved
281 exercise capacity following both the LI and HI warm-up. In-line with previous research, these
282 data suggest that SB supplementation improves high-intensity exercise, the novelty of the
283 current study is that this significant ergogenic effect occurs following either a LI or HI warm-
284 up. However, evidence was not obtained to support our hypothesis that performance capacity
285 would be further improved with a HI vs. LI warm-up with or without bicarbonate
286 supplementation (Figure 2).

287

288 The magnitude of the blood bicarbonate increase following SB ingestion and prior to the warm-
289 up is in line with those previously reported with an identical dose (Bishop, Edge, Davis, &
290 Goodman, 2004; Jones et al., 2016; McNaughton, 1992; Saunders et al., 2014). Warm-up
291 always reduced blood bicarbonate, with greater reductions following HI than LI; lactate was
292 also increased to a greater extent with the HI warm-up, confirming the greater intensity of the
293 activity. Greater decreases in blood bicarbonate and greater increases in lactate were shown
294 with SB compared to PLA following the warm-up, regardless of warm-up intensity. This likely
295 reflects an increased efflux of lactate and H⁺ out of the working muscle (Juel, 1997), with a
296 subsequent increased buffering of the H⁺. Pre-CCT_{110%} bicarbonate levels remained increased
297 compared to baseline with SB (LI: 4.7mmol·L⁻¹; HI: 2.7mmol·L⁻¹), resulting in an improved
298 exercise capacity compared to PLA. These data can explain the ergogenic effects of SB shown
299 herein, although it contradicts the recently held belief that a minimum threshold +5mmol·L⁻¹

300 increase in blood bicarbonate is necessary to elicit an ergogenic effect (Carr, Slater, Gore,
301 Dawson, & Burke, 2011). Although the minimal increase necessary to elicit an ergogenic effect
302 is currently unknown (Heibel, Perim, Oliveira, McNaughton, & Saunders, 2018), theoretically,
303 even minimal increases in circulating bicarbonate would correspond to increases in buffering
304 capacity. One might expect that the greater bicarbonate concentration would allow the
305 individual to perform at a greater intensity for a longer duration, eventually reaching the same
306 acidotic endpoint (*i.e.*, equally depleted bicarbonate and low pH). The current data provide
307 evidence that only small increases in blood bicarbonate are necessary to elicit performance
308 benefits, while further work should investigate what factors limit complete utilisation of the
309 increased buffering capacity with SB.

310

311 To ensure high ecological validity, both the HI warm-up and the 30-minute recovery period
312 were implemented to replicate a typical elite track-cycling protocol (*personal observations, T.*
313 *Stellingwerff*), and to reflect the athlete pre-competition / post warm-up “check-in” constraints
314 at international competitions for most high-intensity sports (e.g., Cycling, Athletics, Swimming
315 etc). Interestingly, our novel data showed that there was a restoration, or “rebound”, of blood
316 bicarbonate in all sessions following the warm-up, suggesting this is a normal physiological
317 response towards homeostasis, albeit it appears that SB ingestion impacts this response. This
318 response aligns with recovery in acid base balance following intense exercise when sodium
319 bicarbonate has been ingested (Robergs et al., 2005; Gough et al., 2019). Ingestion of SB
320 influenced the blood bicarbonate response during this short 30-minute transition phase; greater
321 increases were shown following SB ingestion with bicarbonate concentrations returning to
322 ~90% of pre-warm-up levels and being significantly increased compared to baseline, whereas
323 they remained below baseline levels for PLA. Interestingly, there was a reduced bicarbonate
324 rebound in the LI conditions (SB: $+7.8\text{mmol}\cdot\text{L}^{-1}$; PLA: $+5.8\text{mmol}\cdot\text{L}^{-1}$) compared to HI

325 conditions (SB: $+11.2\text{mmol}\cdot\text{L}^{-1}$; PLA: $+8.2\text{mmol}\cdot\text{L}^{-1}$); probably due to the already higher
326 bicarbonate concentrations following the LI warm-up. These data indicate that the post-
327 exercise recovery of bicarbonate concentration is influenced by both SB supplementation and
328 warm-up intensity. Increased bicarbonate recovery kinetics with SB were likely due to residues
329 from supplementation continuing to affect circulating bicarbonate, since blood bicarbonate
330 remains increased more than 3 h following supplementation (Jones et al., 2016). The
331 homeostatic mechanism explaining the bicarbonate rebound without SB, and the positive
332 influence of warm-up intensity on these responses, remains unclear and may be related to
333 lactate/proton exchange and removal abilities that are influenced by exercise intensity (Chatel
334 et al., 2016), increased bicarbonate reabsorption (Cogan, Maddox, Lucci, & Rector, 1979) and
335 respiratory compensation (Feher, 2012). Further work should investigate the factors that
336 determine the immediate rebound response of blood bicarbonate following both HI and LI
337 exercise.

338

339 The effects of SB on cycling capacity during the CCT_{110%} has been shown to be highly variable
340 (Saunders et al., 2014) and inconsistent (Froio de Araujo Dias et al., 2015) when using non-
341 specifically trained individuals. In the current investigation, there was a large and significant
342 ~20% increase in cycling capacity (TWD) with SB compared to PLA (Figure 2). The
343 proportion of response analysis estimated that between 80 and 100% of individuals
344 representative of the population studied would be expected to improve TWD beyond the SWC
345 as a direct result of supplementation. These improvements are also in excess of those shown
346 with beta-alanine supplementation [$+5\text{-}14\%$ cycling capacity (Sale et al., 2011; Saunders et al.,
347 2017)], which increases intracellular buffering capacity. Perhaps both warm-ups employed
348 here induced a greater positive performance capacity influence from supplementation than the
349 aforementioned studies, which used a short duration (5-minute) low-intensity fixed load warm-

350 up with little recovery time (2-3-minute) prior to the main exercise bout. This may have
351 influenced results since the effectiveness of a warm-up will be determined by both its intensity
352 and duration, and the subsequent recovery period prior to the main exercise task (McGowan et
353 al., 2015). The recovery period in previous studies may not have been of sufficient length to
354 allow blood variables to return to optimal levels, which would have optimised exercise
355 capacity. Based upon the current data, the practice of ingesting SB to elicit an ergogenic effect
356 on exercise performance can be beneficial when undertaking a HI or LI warm-up 30-minutes
357 prior to the event.

358

359 The present study showed similar effects of low and high intensity warm-ups on exercise
360 capacity, which is in contrast to research showing that undertaking prior HI activity can
361 improve subsequent HI exercise performance (Burnley et al., 2005). The two warm-up
362 intensities were chosen to elicit different blood lactate responses, the HI warm-up aimed to
363 produce blood lactate responses of $+3-5\text{mmol}\cdot\text{L}^{-1}$, where subsequent performance may be
364 improved (Ingham et al., 2013), whilst the LI warm-up aimed to remain below this level.
365 Although warm-ups were conducted at relative exercise intensities, both warm-ups may have
366 been too intense for the non-athlete volunteers since lactate levels immediately post-warm-up
367 were well above $6\text{mmol}\cdot\text{L}^{-1}$ in all sessions. Bishop (2003) reported that warm-ups consisting
368 of workloads above 60% $\text{VO}_{2\text{max}}$ may have an adverse effects on subsequent exercise
369 performance, likely due to the depletion of high-energy phosphates and the accumulation of
370 H^+ . Nonetheless, prior high-intensity exercise can improve exercise tolerance to subsequent
371 high-intensity activity if adequate recovery time is provided ($>9\text{-min}$; (Bailey et al., 2009)).
372 More specifically, for athletes whose competition requires a high-intensity component, warm-
373 ups that elicit a $4-6\text{mmol}\cdot\text{L}^{-1}$ increase in lactate followed by a 20-40-minute recovery period is
374 commonplace (Ingham et al., 2013). Despite the substantial recovery period in this study (30-

375 minute), blood lactate following the HI warm-up remained high and did not return below
376 $4\text{mmol}\cdot\text{L}^{-1}$ in either SB ($6.1\text{mmol}\cdot\text{L}^{-1}$) or PLA ($4.1\text{mmol}\cdot\text{L}^{-1}$). This may explain the lack of a
377 beneficial effect of the HI warm-up, as prior exercise may only improve performance if it elicits
378 a degree of lactic acidosis of less than $3\text{mmol}\cdot\text{L}^{-1}$ when the main exercise bout begins
379 (McGowan et al., 2015). This is also reflected in the similar pre-exercise bicarbonate
380 concentrations between warm-ups, irrespective of supplementation; bicarbonate concentration
381 was similarly reduced from baseline without supplementation following the HI and LI warm-
382 up. Thus, a warm-up that is conducted at too high an intensity may result in a reduced buffering
383 capacity, while there may also be an associated reduction in accumulated oxygen deficit and
384 impairment in performance (Bishop, 2003). The intensity of both the HI and LI warm-up for
385 these individuals may be a limitation of this study and further work should determine the
386 interaction of SB supplementation and warm-up intensity on subsequent exercise in trained
387 individuals.

388

389 In conclusion, the present data show that SB can improve high-intensity cycling capacity
390 irrespective of prior warm-up intensity, likely due to increased blood alkalosis. Since it is
391 commonplace for elite athletes to combine both SB ingestion and a HI warm-up prior to
392 exercise performance, the current investigation provides relevant insight and confirms the
393 efficacy of this practice. Both supplementation and warm-up intensity modified the recovery
394 kinetics of the measured blood variables, highlighting several potential avenues of future
395 research, specifically regarding the blood analyte responses during the transition period
396 between warm-up and exercise.

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527 **FIGURES**

528 Figure 1: Experimental protocol for the main trials. SB: Sodium bicarbonate, PLA: Placebo.
529 HI: High intensity, LI: Low intensity. CCT110%: cycling capacity test to exhaustion at 110%
530 W_{\max} .

531

532 Figure 2: Total Work Done (TWD) across the four conditions; HIPLA: High intensity warm-
533 up with placebo, HISB: High intensity warm-up with sodium bicarbonate, LIPLA: Low
534 intensity warm-up with placebo, LISB: Low intensity warm-up with sodium bicarbonate. Data
535 are Means \pm SD while individual data points are also plotted.

536

537 Figure 3: Group bicarbonate data modelled across study using mixed level model. HIPLA:
538 High intensity warm-up with placebo, HISB: High intensity warm-up with sodium bicarbonate,
539 LIPLA: Low intensity warm-up with placebo, LISB: Low intensity warm-up with sodium
540 bicarbonate. WU: Warm-up, CCT110%: cycling capacity test to exhaustion at 110% W_{\max} .
541 Error bars are centred at group average and represent standard errors.

542

543 Figure 4: Group lactate data modelled across study using mixed level model. HIPLA: High
544 intensity warm-up with placebo, HISB: High intensity warm-up with sodium bicarbonate,
545 LIPLA: Low intensity warm-up with placebo, LISB: Low intensity warm-up with sodium
546 bicarbonate. WU: Warm-up, CCT110%: cycling capacity test to exhaustion at 110% W_{\max} .
547 Error bars are centred at group average and represent standard errors.