

1 **Title:** Post-exercise supplementation of sodium bicarbonate improves  
2 acid base balance recovery and subsequent high-intensity boxing  
3 specific performance  
4

5 **Authors:** Dr Lewis A. Gough<sup>1, 3</sup>, Mr Steven Rimmer<sup>2</sup>, Dr S. Andy Sparks<sup>3</sup>, Professor Lars R.  
6 McNaughton<sup>3, 4</sup> and Dr Matthew F. Higgins<sup>2\*</sup>  
7

8 **Affiliations:**

9 <sup>1</sup> Research Centre for Life and Sport Sciences (CLaSS), School of Health Sciences, Department  
10 of Sport and Exercise, Birmingham City University, B15 3TN.

11 <sup>2</sup> Human Sciences Research Centre, University of Derby, Kedleston Road, Derby, DE22 1GB

12 <sup>3</sup> Sports Nutrition and Performance Group, Department of Sport and Physical Activity, Edge  
13 Hill University, Lancashire L39 4QP, UK

14 <sup>4</sup> Department of Sport and Movement Studies, Faculty of Health Science, University of  
15 Johannesburg, Johannesburg, South Africa.  
16

17 **Corresponding Author:**

18 Dr. Matthew F. Higgins: Human Sciences Research Centre, University of Derby, Kedleston  
19 Road, Derby, DE22 1GB. Tel: +44 (0) 1332 591743 Email: m.higgins@derby.ac.uk  
20

21 **Abstract**

22 The aim of this study was to assess the effects of post-exercise sodium bicarbonate (NaHCO<sub>3</sub>)  
23 ingestion (0.3 g.kg<sup>-1</sup> body mass) on the recovery of acid-base balance (pH, HCO<sub>3</sub><sup>-</sup>, and the SID)  
24 and subsequent exercise performance in elite boxers. Seven elite male professional boxers  
25 performed an initial bout of exhaustive exercise comprising of a boxing specific high-intensity  
26 interval running (HIIR) protocol, followed by a high-intensity run to volitional exhaustion  
27 (T<sub>LIM1</sub>). A 75 min passive recovery then ensued, whereby after 10 min recovery, participants  
28 ingested either 0.3 g.kg<sup>-1</sup> body mass NaHCO<sub>3</sub>, or 0.1 g.kg<sup>-1</sup> body mass sodium chloride (PLA).  
29 Solutions were taste matched and administered double-blind. Participants then completed a  
30 boxing specific punch combination protocol, followed by a second high-intensity run to  
31 volitional exhaustion (T<sub>LIM2</sub>). Both initial bouts of T<sub>LIM1</sub> were well matched between PLA and  
32 NaHCO<sub>3</sub> (ICC;  $r = 0.94$ ,  $p = 0.002$ ). The change in performance from T<sub>LIM1</sub> to T<sub>LIM2</sub> was greater  
33 following NaHCO<sub>3</sub> compared to PLA ( $+164 \pm 90$  vs.  $+73 \pm 78$  sec;  $p = 0.02$ , CI = 45.1, 428.8,  
34  $g = 1.0$ ). Following ingestion of NaHCO<sub>3</sub>, pH was greater prior to T<sub>LIM2</sub> by  $0.11 \pm 0.02$  units  
35 (1.4%) ( $p < 0.001$ , CI = 0.09, 0.13,  $g = 3.4$ ), whilst HCO<sub>3</sub><sup>-</sup> was greater by  $8.8 \pm 1.5$  mmol.l<sup>-1</sup>  
36 (26.3%) compared to PLA ( $p < 0.001$ , CI = 7.3, 10.2,  $g = 5.1$ ). The current study suggests that  
37 these significant increases in acid base balance during post-exercise recovery facilitated the  
38 improvement in the subsequent bout of exercise. Future research should continue to explore  
39 the role of NaHCO<sub>3</sub> supplementation as a recovery aid in boxing and other combat sports.

40 **Key Words:**

41 **Buffering, alkalosis, acid base balance, combat sports, recovery, nutrition, training**

## 42 **Introduction**

43 High levels of glycolytic flux are essential to maintain the required physiological output  
44 during combat exercise (Franchini et al., 2011), although a concomitant fall in both muscle and  
45 blood pH and bicarbonate ion concentration ( $[\text{HCO}_3^-]$ ) eventually occurs (Fitts, 1994). This is  
46 due to the increases in hydrogen ion ( $\text{H}^+$ ) accumulation, which in turn, disturb the state of  
47 equilibrium between acidity and alkalinity of body fluids (i.e. acid base balance). Such an  
48 alteration is known as metabolic acidosis and has been associated with fatigue by reducing or  
49 impairing the release of calcium ions ( $\text{Ca}^{2+}$ ) from the sarcoplasmic reticulum (Messonnier,  
50 Kristensen, Juel & Denis, 2007), impeding glycolytic enzyme activity (Atherton, 2003), and  
51 altering the strong ion difference leading to reduced action potentials and muscle excitability  
52 (Sostaric et al., 2006). The typical daily regimen for a competitive boxer often consists of two  
53 sessions comprised of an initial high-intensity intermittent running session followed by a  
54 boxing-specific session that mimics the demands of competition, interspersed within a short  
55 recovery period (Morton, Robertson, Sutton and Maclaren, 2010). Subsequently a large degree  
56 of metabolic acidosis is likely evident in the subsequent bout of exercise, therefore mitigation  
57 of the deleterious effects between sessions are prudent to investigate.

58 Pre-exercise ingestion of  $0.3 \text{ g.kg}^{-1}$  body mass (BM) sodium bicarbonate ( $\text{NaHCO}_3$ )  
59 can lead to an approximate increase in pH ( $+0.07 \pm 0.01$ ) and  $\text{HCO}_3^-$  from baseline ( $+3.9 \pm 0.9$   
60  $\text{mmol.l}^{-1}$ ), eliciting a state of metabolic alkalosis (Carr, Hopkins and Gore, 2011). Ergogenic  
61 effects have been reported in combat sports including boxing (Siegler and Hirscher, 2010) and  
62 judo (Artioli et al., 2007; Felipe, Lopes-Silva, Bertuzzi, McGinley & Lima-Silva, 2016) by  
63 either increasing punches landed or total work done (TWD). Whilst the effects of pre-exercise  
64  $\text{NaHCO}_3$  ingestion has been well researched (for review see McNaughton et al., 2016), the  
65 effects of post-exercise ingestion between two bouts of exercise to promote recovery has  
66 received minimal attention. The use of this alternative method might permit a greater observed  
67 improvement in acid base balance during the recovery period, whilst the enhanced level of acid  
68 base balance would not have been utilised within the initial bout of exercise. These factors  
69 combined might therefore increase performance during the subsequent bout of exercise  
70 compared to pre-exercise  $\text{NaHCO}_3$  ingestion. Indeed, Gough et al. (2017) reported that  $0.3$   
71  $\text{g.kg}^{-1}$   $\text{NaHCO}_3$  ingested 30 mins into a 90 min post-exercise recovery period improved  
72 subsequent cycling time to volitional exhaustion by 33 secs (~14%) in recreationally active  
73 individuals. It is likely that an enhanced level of acid base balance was the primary mechanism  
74 for such an improvement, as the authors reported marked increases in pH and  $\text{HCO}_3^-$  prior to

75 the second bout of exercise compared to the placebo (pH = +0.07, effect size (ES) = 2.6,  $\text{HCO}_3^-$   
76 = +7  $\text{mmol}\cdot\text{l}^{-1}$ , ES =3.4). It is unknown, however, if these positive findings translate to other  
77 exercise modalities such as boxing, and individuals of a higher training status.

78 The mechanisms to explain the performance improvement following  $\text{NaHCO}_3$   
79 supplementation is not unique to changes in pH and  $\text{HCO}_3^-$ . Specifically, marked ionic shifts  
80 are suggested to contribute to muscle fatigue by impeding maximal  $\text{Na}^+$ ,  $\text{K}^+$ -ATPase activity,  
81 subsequently impairing cell membrane excitability (Fitts, 1994; Stephens, McKenna, Canny,  
82 Snow & McConell, 2002; Sostaric et al., 2006). Indeed, both large effluxes of extracellular  $\text{K}^+$   
83 concomitant with reductions in  $\text{Na}^+$  have been suggested to exacerbate the  $\text{K}^+$  induced decline  
84 in force production (Bouclin et al., 1995). Pre-exercise ingestion of  $\text{NaHCO}_3$  has been shown  
85 to reduce  $\text{K}^+$  and increase  $\text{Na}^+$  prior to the onset of exercise (Sostaric et al., 2006; Siegler and  
86 Hirscher, 2010; Stephens et al., 2002; Jones et al., 2016). Indeed, Siegler and Hirscher (2010)  
87 reported  $\text{NaHCO}_3$  supplementation prior to a simulated boxing protocol lowered  $\text{K}^+$  compared  
88 to the placebo condition ( $4.0 \pm 0.1 \text{ mEq}\cdot\text{l}^{-1}$  vs.  $5.3 \pm 0.4 \text{ mEq}\cdot\text{l}^{-1}$ , respectively) and subsequently  
89 speculated that this reduction might have facilitated the resulting performance improvement. It  
90 is widely argued however, that electrolyte balance should be assessed by the collective analysis  
91 of the strong ion difference (SID), which is the balance of the fully dissociated cations and anions  
92 in intracellular and extracellular fluid (Stewart, 1983). Synergistic changes in electrolytes are  
93 suggested to allow for deeper assessment of fatigue mechanisms, as opposed to reporting  
94 changes within a single electrolyte. In the only study to date, Gough et al. (2018a) reported a  
95 significant increase in the SID following  $\text{NaHCO}_3$  supplementation and an improvement in 2  
96 x 4 km time trial cycling bouts interspersed by 40 min recovery, although this study was  
97 conducted in a normobaric hypoxic environment. The purpose of this study therefore was to  
98 investigate the effects of post-exercise ingestion of  $\text{NaHCO}_3$  on acid base balance recovery,  
99 the SID and subsequent boxing performance.

100

## 101 **Materials and methods**

102 Seven male elite professional boxers (age:  $27.1 \pm 5.1$  years, stature:  $175.8 \pm 5.7$  cm,  
103 body mass:  $72.2 \pm 10.3$  kg, relative peak oxygen uptake ( $\dot{V}\text{O}_{2\text{peak}}$ ):  $55.8 \pm 11.4 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ )  
104 from various boxing weight classifications including flyweight, lightweight, junior  
105 welterweight (WBO/IBF) super lightweight (WBA/WBC), middleweight & super  
106 middleweight completed this study. Participants were considered elite standard boxers and

107 were at least Commonwealth (British Empire), English, International Masters, British Masters,  
108 or Midlands Area title holders, with an average of  $4.1 \pm 3.6$  years professional boxing  
109 experience. At the time of data collection, all participants were in pre-competition training. The  
110 study received institutional ethics committee approval (University of Derby, UK) prior to any  
111 testing, and participants were informed of the details of the study, both verbally and in writing,  
112 prior to providing written informed consent in accordance with the Declaration of Helsinki.  
113 Physical Activity Readiness Questionnaire (PAR-Q) and blood analysis questionnaires were  
114 completed prior to each bout of exercise.

115

### 116 **Preliminary procedures**

117 Prior to each trial, participants were requested to avoid strenuous exercise and to abstain  
118 from caffeine and alcohol ingestion for at least 24 hours. Participants were also encouraged to  
119 adopt the same mixed balanced diet with adherence monitored through a food diary, which  
120 participants recorded 24 hours prior to testing. A photocopy of the food diary was given to each  
121 participant to facilitate dietary replication prior to each experimental trial with 100% adherence  
122 achieved. Finally, participants were verbally screened to ensure they had refrained from  
123 ingestion of ergogenic buffers such as sodium citrate and  $\beta$ -alanine for 6 months prior to  
124 beginning the study.

125 Participant's body composition was assessed using Dual Energy X-ray Absorptiometry  
126 (Lunar iDXA, GE Healthcare, Hertfordshire, UK) 7-10 days prior to the experimental trials for  
127 analysis of body mass (kg). During the same visit, following 3 hours of fasting, participants  
128 completed an incremental exercise test on a motorised treadmill (Desmo, Woodway, Germany)  
129 to assess peak oxygen uptake ( $\dot{V}O_{2\text{peak}}$ ). Initially participants warmed up for 5 min at  $8 \text{ km}\cdot\text{h}^{-1}$   
130 with a 0% gradient. The test began with a 3 minute stage at  $10 \text{ km}\cdot\text{h}^{-1}$ , subsequently the speed  
131 increased by  $2 \text{ km}\cdot\text{h}^{-1}$  every three min until it reached the  $16 \text{ km}\cdot\text{h}^{-1}$  stage. From this point the  
132 gradient was increased by 2% every 2 min until volitional exhaustion. Throughout the test  
133 expired gas samples were collected via an online breath by breath system (Cortex MetaLyzer  
134 II, Biophysik, Leipzig, Germany) which was calibrated before each test as per the  
135 manufacturer's guidelines. Expired gas samples were analysed for oxygen consumption ( $\dot{V}O_2$ ),  
136 carbon dioxide production ( $\dot{V}CO_2$ ) and respiratory exchange ratio (RER). The highest value of  
137  $\dot{V}O_2$  obtained in any 30 second period was used to calculate  $\dot{V}O_{2\text{peak}}$ .

138

139 **Familiarisation**

140 During the second laboratory visit participants were familiarised with the high intensity  
141 interval run (HIIR) protocol (Table 1), and the punch type techniques and combinations (Table  
142 2), that would be utilised during experimental trials. In the HIIR, emphasis was placed upon  
143 exercising at a percentage of running velocity at  $\dot{V}O_{2peak}$  during each differing work interval as  
144 opposed to heart rate ensuring the total time at each workload was readily matched. Finally,  
145 participants ran at a velocity that elicited 90%  $\dot{V}O_{2peak}$  to volitional exhaustion ( $T_{LIM}$ ) as a  
146 measure of high-intensity endurance capacity.

147

148 \*\*\* Tables 1 and 2 about here \*\*\*

149

150 **Experimental Design and Protocol**

151 Experimental trials were conducted using a repeated measures, partially  
152 counterbalanced (due to odd number sample size), double-blind, and placebo controlled design,  
153 each separated by seven days. Participants reported for each trial three hours postprandial and  
154 at the same time of day to avoid any circadian rhythm effects on performance (Forbes-  
155 Robertson, Dudley, Vadgama, Cook, Drawer & Kilduff, 2012). Body mass was measured and  
156 recorded at the start of each laboratory visit (Seca 761 weight scales, Birmingham, UK), to  
157 monitor possible fluctuations between experimental trials due to the participants being in pre-  
158 competition training stages. The following baseline measures were obtained after 5 min seated  
159 rest: heart rate (HR; (Polar, FT40, Finland), blood lactate concentration ( $[La^-]$ ), base excess  
160 (BE), bicarbonate ion concentration ( $[HCO_3^-]$ ) and a range of electrolytes (sodium  $[Na^+]$ ,  
161 potassium  $[K^+]$ , calcium  $[Ca^{2+}]$  and chloride  $[Cl^-]$ ). The electrolyte data was used to calculate  
162 the apparent SID using an online spreadsheet (Lloyd, 2004) based on the following formula:  
163  $[K^+] + [Na^+] + [Ca^{2+}] + [Na^+] - [Cl^-] - [La^-]$ . Blood variables were collected via a finger prick  
164 capillary blood sample and analysed with a blood gas analyser (ABL90 Flex, Radiometer, West  
165 Sussex, UK). Perceived readiness to exercise (PRE) was then recorded against an 11 point (0-  
166 10) scale with 0 representing 'not at all ready to exercise' and 10 representing 'completely  
167 ready to exercise' (Higgins et al., 2013).

168 Exercise trials commenced with a 5 minute treadmill run at a velocity eliciting ~60%  
169  $\dot{V}O_{2PEAK}$  (warm-up) immediately followed by the HIIR protocol (Table 1) which was repeated  
170 three times to imitate the demands of 3x4 minute boxing rounds, each separated by 60 sec

171 active recovery. A self-selected active recovery was recorded and replicated for each recovery  
172 interval in both experimental trials. Subsequently, a fourth and final bout was performed on a  
173 treadmill at a running velocity eliciting  $\sim 90\%$   $\dot{V}O_{2PEAK}$  to volitional exhaustion ( $T_{LIM1}$ ) with  
174 participants blinded from distance and time completed. Overall (i.e. related to cardiovascular  
175 strain) ratings of perceived exertion ( $RPE_O$ ) (Borg scale 6-20; 1982) were recorded within the  
176 final 5 sec of each round. Immediately post-exercise HR and  $RPE_O$  were recorded. Five min  
177 post-exercise HR and blood metabolite/electrolyte data was collected as previously described.

178 Participants then recovered passively for 75 min prior to undertaking subsequent  
179 boxing performance. This was selected due to previous data showing this time period is  
180 approximately when acid base balance returns to baseline following high-intensity exercise  
181 (Gough et al., 2017). Ten minutes into recovery, participants consumed either  $0.3 \text{ g}\cdot\text{kg}^{-1}$  body  
182 mass of  $\text{NaHCO}_3$  or  $0.1 \text{ g}\cdot\text{kg}^{-1}$  body mass of sodium chloride (placebo; PLA) within a  
183 standardised five minute period. **This time period was selected due to the fear of vomiting if**  
184 **ingestion began immediately post-exercise, whilst a longer time period was not used as this**  
185 **may have allowed acid base balance to recover back to baseline values prior to ingestion**  
186 **(Gough et al., 2017).** Both drinks were mixed in  $4 \text{ ml}\cdot\text{kg}^{-1}$  body mass tap water and  $1 \text{ ml}\cdot\text{kg}^{-1}$   
187 body mass of double strength no added sugar orange squash (Sainsbury's, London, U.K.)  
188 (Higgins et al., 2013). Thirty min post exercise abdominal discomfort (AD) and gut fullness  
189 (GF) were recorded using an 11 point (0-10) scale, with 0 representing 'empty' and 'completely  
190 comfortable', and 10 representing 'bloated' and 'unbearable pain' respectively (Higgins et al.,  
191 2013). Water was consumed *ad libitum* during recovery (mean  $582 \pm 40 \text{ ml}$ ).

192 At the end of the 75 minute recovery, HR, PRE, blood metabolites/electrolytes, AD and  
193 GF were all recorded prior to participants performing a 5 min standardised dynamic warm up.  
194 Participants then completed the boxing specific protocol (Table 2) whereby they were required  
195 to strike the focus pads (Serious, Rapid Fire Punch Mitts, London, UK), which were worn by  
196 the same researcher for all trials. Each complete cycle consisted of 21 punches with participants  
197 instructed to stay in their preferred boxing stance (orthodox or southpaw) throughout. The  
198 punch combination cycle was performed repeatedly for 3x3 minute rounds, each separated by  
199 60 sec passive recovery. Participants were all given the same boxing gloves (10 oz, Adidas,  
200 Hi-Tech Multi-Boxing Glove, Germany) for both experimental trials. An audio and visual  
201 boxing gym timer (Title Boxing, De luxe gym timer, USA) kept timing of rounds. Immediately  
202 at the end of each round participants HR,  $RPE_O$  and ratings of perceived exertion localised to  
203 the arms ( $RPE_A$ ; Borg scale 6-20) were recorded. Upon completion of the 3 boxing specific

204 rounds AD and GF were also recorded. Following a 60 second rest period, participants then  
205 performed a final high intensity treadmill run corresponding to a speed that elicited ~90%  
206  $\dot{V}O_{2peak}$  to volitional exhaustion ( $T_{LIM2}$ ). Immediately post exercise HR, RPE<sub>O</sub>, AD and GF  
207 were recorded, and five min post-exercise HR, blood metabolite/electrolytes, AD and GF were  
208 recorded.

209

## 210 **Statistical analysis**

211 Data was firstly checked for normality via a Shapiro-Wilk test, followed by a Mauchly  
212 test for homogeneity of variance/sphericity. A paired t test was used for some performance  
213 ( $T_{LIM1}$  and  $T_{LIM2}$ ) and blood/perceptual data (change in  $HCO_3^-$  during  $T_{LIM2}$ , change in  $HCO_3^-$   
214 during recovery, and aggregated GI discomfort). A two-way [treatment  $\times$  time] repeated  
215 measures ANOVA was conducted with a Bonferroni correction for changes in blood variables  
216 (pH,  $HCO_3^-$  and lactate). Effect size (ES) for interactions from the ANOVA are reported as  
217 partial eta squared ( $P\eta^2$ ), whilst between treatment ES are reported as Hedge's g effect sizes  
218 (g) (interpreted as per conventional thresholds described by Cohen 1988). If  $p < 0.05$  then 95%  
219 CI are reported, where changes that do not cross the zero boundary treated as significant. A  
220 Friedman test was used for non-normally distributed data (AD, GF), and where the a priori  
221 alpha value was observed (i.e.  $p < 0.05$ ) a post hoc Wilcoxon signed rank-test was conducted  
222 with median, z score, and p value reported. For non-normally distributed data the ES is  
223 calculated by  $Z/\sqrt{n}$  with 0.10, 0.24 and 0.37 considered as small, medium and large effects,  
224 respectively (Ivarsson et al., 2013). Reproducibility of the performance in  $T_{LIM1}$  was assessed  
225 using intraclass correlation coefficients (ICC), with the  $r$  value and significance reported.  
226 **Additional statistics such as confidence intervals and effect sizes were used due to the small**  
227 **sample size in the study, which might not be suited to statistical procedures such as t test and**  
228 **ANOVA in isolation.** Data were analysed using a statistical software package, SPSS (V.24,  
229 IBM Inc., Chicago, IL, USA).

230

## 231 **Results**

### 232 **Performance**

233 Both initial bouts for  $T_{LIM1}$  were well matched between PLA and  $NaHCO_3$  ( $328 \pm 155$   
234 vs  $307 \pm 142$  s; ICC:  $r = 0.94$ ,  $p = 0.002$ ; t test,  $p = 0.526$ ), showing that participants were at a  
235 similar level of fatigue at the start of the recovery period. Performance in  $T_{LIM2}$  was greater by



236 70 ± 90 sec (28%) following NaHCO<sub>3</sub> compared to PLA (p = 0.084, CI = -153.8, 12.9; Figure  
237 1a), with a moderate effect size (g = 0.41). The change in performance from T<sub>LIM1</sub> to T<sub>LIM2</sub> was  
238 greater following NaHCO<sub>3</sub> compared to PLA (+164 ± 90 vs. +73 ± 78 sec; p = 0.02, CI = 45.1,  
239 428.8, g = 1.0; Figure 1b). One participant displayed an ergolytic effect following NaHCO<sub>3</sub>  
240 ingestion, such that T<sub>LIM2</sub> decreased by 13% compared to PLA (545 vs. 623 sec). This  
241 participant also suffered from moderate to severe GI discomfort.

242

### 243 **Blood variables**

244 No differences in pH between PLA and NaHCO<sub>3</sub> were observed at baseline (7.43 ±  
245 0.04 vs. 7.42 ± 0.02; p = 0.233), or post T<sub>LIM1</sub> (7.31 ± 0.04 vs. 7.31 ± 0.04; p = 0.696). Following  
246 the recovery period, and the ingestion of NaHCO<sub>3</sub>, pH was greater prior to T<sub>LIM2</sub> by 0.11 ± 0.02  
247 units (1.4%) (p <0.001, CI = 0.09, 0.13, g = 3.4). Post T<sub>LIM2</sub>, no difference between treatments  
248 was observed for pH (7.31 ± 0.06 vs. 7.33 ± 0.08; p = 0.271; Figure 2a). There were no  
249 differences in HCO<sub>3</sub><sup>-</sup> between PLA and NaHCO<sub>3</sub> at baseline (25.9 ± 1.5 vs. 26.0 ± 1.6 mmol.l<sup>-1</sup>  
250 <sup>-1</sup>; p = 0.750), post T<sub>LIM1</sub> (16.6 ± 2.2 vs. 16.8 ± 2.2 mmol.l<sup>-1</sup>; p = 0.723), or post T<sub>LIM2</sub> (17.7 ±  
251 3.1 vs. 19.0 ± 3.4 mmol.l<sup>-1</sup>; p = 0.196). Following recovery however, HCO<sub>3</sub><sup>-</sup> was greater by 8.8  
252 ± 1.5 mmol.l<sup>-1</sup> (26.3%) post-NaHCO<sub>3</sub> supplementation compared to PLA (p <0.001, CI = 7.3,  
253 10.2, g = 5.1; Figure 2b). The change in HCO<sub>3</sub><sup>-</sup> during recovery (post T<sub>LIM1</sub> to pre T<sub>LIM2</sub>) was  
254 greater following NaHCO<sub>3</sub> ingestion compared to PLA (16.6 ± 1.4 vs. 8.0 ± 2.1 mmol.l<sup>-1</sup>; p  
255 <0.001; CI = 6.5, 10.7, g = 4.5). During T<sub>LIM2</sub>, the change in HCO<sub>3</sub><sup>-</sup> during exercise was greater  
256 for NaHCO<sub>3</sub> compared to PLA (14.3 ± 2.9 vs. 6.9 ± 2.5 mmol.l<sup>-1</sup> p <0.001, 10.3, 4.5, g = 2.5).  
257 Post T<sub>LIM2</sub>, BLA<sup>-</sup> was 5.2 ± 2.6 mmol.l<sup>-1</sup> (39.5%) greater following NaHCO<sub>3</sub> (p = 0.002, CI =  
258 2.6, 7.3, g = 2.0), with no difference at any other time point (p >0.05; Figure 2c).

259 Ingestion of NaHCO<sub>3</sub> caused marked changes in Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup> and Cl<sup>-</sup> (Figure 3). A  
260 time\*treatment interaction was observed for the SID (p = 0.023, Pη<sup>2</sup> = 0.576), such that a 10%  
261 increase in the SID was observed post recovery following NaHCO<sub>3</sub> ingestion compared to PLA  
262 (46 ± 1 vs. 36 ± 4 meq/l; p <0.001, CI = 6.3, 13.7, g = 3.2; Figure 4).

263

### 264 **Heart rate and perceptual measures**

265 Post-exercise ingestion of NaHCO<sub>3</sub> increased HR in rounds 2 and 3 compared to PLA  
266 (p <0.05), whilst no effect was observed on RPE<sub>O</sub> or RPE<sub>A</sub> (p >0.05) during any round of the  
267 HIIR. No effect on post T<sub>LIM2</sub> HR (p = 0.217, g = 0.46) was observed following NaHCO<sub>3</sub>.

268 Likewise, no difference in HR between NaHCO<sub>3</sub> and PLA were observed at any time point  
269 during T<sub>LIM2</sub> (all p >0.05). Similarly, NaHCO<sub>3</sub> supplementation had no effect on post T<sub>LIM2</sub>  
270 RPE<sub>O</sub> (Z = 1.47, p = 0.383), with no difference observed between treatments at any time point  
271 (p >0.05).

272 Abdominal discomfort was greater following NaHCO<sub>3</sub> ingestion at 30 min recovery,  
273 displaying a moderate effect size (3.6 ± 3.0 vs. 1.6 ± 2.3; Z = 1.76, p = 0.07, g = 0.7). At the  
274 end of recovery, abdominal discomfort had generally reduced, although NaHCO<sub>3</sub> was still  
275 greater (1.7 ± 1.7 vs. 0.7 ± 1.3; Z = -1.89, p = 0.06, g = 0.6). No time\*treatment interaction was  
276 observed for gut fullness (p = 0.219, η<sup>2</sup> = 0.213). Aggregated GI discomfort was not  
277 significantly different between NaHCO<sub>3</sub> ingestion and PLA (19 ± 13 vs. 13 ± 15; p = 0.175, -  
278 14.1, 3.2), although it was associated with a moderate effect size (g = 0.40; Figure 5).

279

## 280 Discussion

281 This study investigated the effects of post-exercise NaHCO<sub>3</sub> ingestion on subsequent  
282 high-intensity boxing performance. Following NaHCO<sub>3</sub> ingestion, acid base balance was  
283 increased prior to T<sub>LIM2</sub> compared to PLA which subsequently improved subsequent boxing  
284 specific exercise performance. **Athletes and coaches can therefore implement this strategy to**  
285 **support training at times when multiple bouts of exercise are carried out with limited recovery**  
286 **interspersed.**

287 The findings of the current study show that NaHCO<sub>3</sub> ingestion improved subsequent  
288 boxing specific performance, by markedly reducing the decline from T<sub>LIM1</sub> to T<sub>LIM2</sub>. This adds  
289 to previous work evaluating post-exercise NaHCO<sub>3</sub> supplementation as a recovery supplement  
290 (Gough et al., 2017). Indeed, Gough et al. (2017) showed that NaHCO<sub>3</sub> ingestion 30 min into  
291 a 90 min recovery period improved subsequent cycling capacity, such that a moderate effect  
292 size (g = 0.5) was observed versus the placebo within a group of recreationally trained males.  
293 The current study adds however, similar ergogenic effects can be achieved with post-exercise  
294 NaHCO<sub>3</sub> ingestion within a shorter recovery time, individuals of a higher training status, and  
295 combat exercise. In addition, these findings also support previous literature showing NaHCO<sub>3</sub>  
296 ingestion is an effective supplement to improve combat performance when ingested prior to  
297 exercise (Siegler and Hirscher, 2010; Lopes-Silva et al., 2018). Future research could consider  
298 the impact of NaHCO<sub>3</sub> ingestion to enhance subsequent performance in other combat sports.

299 Based on the observed improvements it can be speculated that if NaHCO<sub>3</sub>  
300 supplementation could be adapted into a chronic weekly supplementation strategy, this might  
301 lead to greater adaptation to training. Previous work by Percival et al. (2015) has shown mRNA  
302 expression of PGC-1a, a known mechanism for mitochondrial adaptation, was increased 3  
303 hours following a high intensity training session with acute NaHCO<sub>3</sub> ingestion compared to a  
304 placebo. Based on this evidence it is plausible that this may aid training adaptation in boxing,  
305 however, the study by Percival et al. (2015) was in cycling and in lesser trained individuals to  
306 the current study (healthy men vs. elite boxers). In addition, other studies investigating the  
307 effects of NaHCO<sub>3</sub> ingestion to support training adaptations are equivocal within trained  
308 individuals. Indeed, Edge, Bishop and Goodman (2006) reported chronic NaHCO<sub>3</sub> ingestion  
309 significantly increased lactate threshold by 11% and time to fatigue (100% VO<sub>2peak</sub>) by 41%  
310 compared to a placebo following 8 weeks of cycling interval training. Both Driller et al. (2013)  
311 and Siegler et al. (2018) however, have shown no greater training adaptations following  
312 NaHCO<sub>3</sub> ingestion within rowing and resistance exercise modalities across 4 weeks and 10  
313 weeks of training, respectively. Considering positive findings have been reported in combat  
314 exercise following NaHCO<sub>3</sub> ingestion (Siegler et al., 2010; Lopez-Silva et al., 2018), further  
315 research could explore if greater training adaptations occur with chronic NaHCO<sub>3</sub> ingestion.

316 In the present study, the likely mechanism to explain the improvement in subsequent  
317 performance is the changes in blood acid base balance between bouts, such that pH, HCO<sub>3</sub><sup>-</sup> and  
318 the SID were significantly higher at 75 min recovery following NaHCO<sub>3</sub> ingestion. Full  
319 recovery of pH, HCO<sub>3</sub><sup>-</sup>, and the SID was achieved in approximately 30-35 min. This is in  
320 contrast to the placebo condition, which failed to recover any of these blood analytes to baseline  
321 within 75 min of recovery. As a result, NaHCO<sub>3</sub> ingestion mitigated the disturbance to acid  
322 base balance during T<sub>LIM2</sub>, which subsequently may explain the performance improvement.  
323 Such a greater state of metabolic alkalosis has been shown to increase buffering capacity by  
324 facilitating efflux of H<sup>+</sup> from the active muscle by enhanced circulating HCO<sub>3</sub><sup>-</sup>, and thus,  
325 increasing the glycolytic energy contribution to high-intensity exercise (Bishop et al., 2004;  
326 Lopes-Silva et al., 2018). The current study supports these mechanisms, reporting a two-fold  
327 increase in the HCO<sub>3</sub><sup>-</sup> change during T<sub>LIM2</sub>, and a marked increase in lactate post-T<sub>LIM2</sub>  
328 following NaHCO<sub>3</sub> ingestion. Indeed, Lopes-Silva et al. (2018) showed similar changes in  
329 post-exercise lactate following NaHCO<sub>3</sub> ingestion, but also reported a significant 31% increase  
330 in estimated glycolytic activity during simulated taekwondo combat. It is important to note  
331 however, the link between metabolic acidosis and fatigue has been widely criticised, suggesting

332 at physiologically valid muscle temperatures, accumulation of  $H^+$  has limited effects on muscle  
333 contractile ability (Westerblad, 2016). As the current study did not assess either temperature or  
334 metabolite accumulation in muscle, we cannot confirm that acidosis has a direct impact on  
335 fatigue and performance.

336 An alternative mechanism to explain the performance improvement might be the  
337 increases in the SID following  $NaHCO_3$  ingestion. Reductions in  $K^+$  and  $Cl^-$  were observed,  
338 whilst  $Na^+$  was increased in the recovery period, which lead to an overall increase in the SID.  
339 This could lead to an increase in electrical excitation, membrane potentials and muscle action  
340 potentials, which in turn, could support maximal  $Na^+$ ,  $K^+$ -ATPase activity (Fitts, 1994; Cairns  
341 and Lindinger, 2008). Previous research, however, has suggested the most important electrolyte  
342 change is  $K^+$ , by demonstrating that raised extracellular concentration depresses muscle  
343 excitability (Cairns and Lindinger, 2008). This suggests that the important changes that  
344  $NaHCO_3$  supplementation elicits is in  $K^+$ . Nonetheless, shifts in  $Cl^-$  similar to those observed  
345 in the present study have been suggested to drive  $K^+$  back to the muscle fibre through inward  
346 rectifier channels, which assist in returning the cell back to resting membrane potential  
347 (Lindinger and Heigenhauser, 1991). A well-designed study by Bouclin et al. (1995) also  
348 showed that when an increased  $K^+$  and reduced  $Na^+$  were altered in combination, the effects on  
349 twitch and tetanic contractions were greater than the changes in these ions in isolation. It is  
350 more likely therefore, that collective changes in electrolyte regulation explain the ergogenic  
351 mechanism of  $NaHCO_3$  supplementation. Further research should therefore continue to explore  
352 the effects of  $NaHCO_3$  supplementation on the SID and exercise performance.

353 One individual presented moderate to high GI discomfort following  $NaHCO_3$  ingestion  
354 and displayed an ergolytic effect on performance. These findings agree with prior  
355 investigations suggesting GI discomfort might be a factor that negates the performance  
356 improvement from  $NaHCO_3$  (Saunders et al., 2014; Cameron et al., 2010; Deb et al., 2018).  
357 Indeed, Saunders et al. (2014) reported upon removing participants who suffered GI discomfort  
358 following  $NaHCO_3$  ingestion, only then did total work done (TWD) improve ( $p = 0.01$ ,  $d =$   
359  $0.25$ ) compared to when all participants were included ( $p = 0.16$ ,  $d = 0.14$ ). However,  
360 performance benefits in combination with the onset of GI discomfort have occurred previously,  
361 whilst there is a lack of a direct link between GI discomfort and exercise performance following  
362  $NaHCO_3$  ingestion (Higgins et al., 2013; Gough et al., 2018b). Individuals that suffer from  
363 severe GI discomfort could benefit from a lower dose of  $NaHCO_3$ , as  $0.2 \text{ g.kg}^{-1} \text{ BM } NaHCO_3$   
364 has been shown to produce similar ergogenic responses whilst significantly reducing GI

365 discomfort (Gough et al., 2018b). Alternatively, the athlete could consider gastric bypass  
366 methods of delivery (i.e. enteric coated capsules), as novel data has suggested this may be  
367 suitable to reduce GI discomfort but still achieve the required increase in acid base balance  
368 (Oliveira et al., 2018; Hilton et al., 2019); although the performance responses are currently  
369 unclear. Further research should explore both lower doses of NaHCO<sub>3</sub> and the use of gastric  
370 bypass methods of delivery to understand the link between GI discomfort and performance  
371 following NaHCO<sub>3</sub> ingestion.

372 A limitation of this study is the small sample size, meaning further work is required to  
373 establish the impact of manipulating post-exercise acid base balance on performance and  
374 recovery. Despite this, the participant cohort were of an elite standard which are typically  
375 difficult to access. The current study findings therefore still have high practical application in  
376 sports performance, although further research with larger sample sizes are required. These  
377 findings compliment previous research investigating NaHCO<sub>3</sub> supplementation and exercise  
378 performance within lesser-trained combat athletes (Artioli et al., 2007; Tobias et al., 2013;  
379 Lopes-Silva et al., 2017) and support the use of NaHCO<sub>3</sub> supplementation to promote superior  
380 recovery.

### 381 **Conclusion**

382 The use of NaHCO<sub>3</sub> is a suitable ergogenic aid to achieve a greater magnitude of acid  
383 base balance recovery and improve subsequent boxing performance within elite level boxers.  
384 Being the first study to assess this within an elite participant cohort, the results of this study are  
385 of significance to athletes and coaches in an applied setting. **Boxers within the elite category**  
386 **could therefore implement this strategy to augment training performance and potentially the**  
387 **subsequent adaptations. One participant did present ergolytic effects following NaHCO<sub>3</sub>**  
388 **ingestion however, which seemed to be due to high GI discomfort. Athletes should therefore**  
389 **trial NaHCO<sub>3</sub> ingestion to assess individual tolerability.** Future research should implement  
390 similar recovery interventions within a larger sample of elite athletes to explore the  
391 effectiveness of NaHCO<sub>3</sub> supplementation as a recovery strategy.

392

### 393 **Acknowledgements**

394 We would like to thank the participants for their time and efforts in this study.

395

396 **Author contributions statement**

397 This study was conceived by MFH and designed by MFH and SR; data were collected by SR  
398 and analysed by LAG and MFH; data interpretation and manuscript preparation were  
399 undertaken by LAG, MFH, LRM, and AS. All authors approved the final version of the paper.

400

401 **Conflict of interest statement and funding disclosure**

402 None of the authors have any financial interest or benefit arising from the direct applications  
403 of this research and there is no conflict of interest. No funding was provided for this study.

404

405 **List of figures**

406 **Figure 1** Overview of performance responses following NaHCO<sub>3</sub> or PLA. \* = NaHCO<sub>3</sub> greater  
407 than PLA (p <0.05). A = changes between T<sub>LIM1</sub> and T<sub>LIM2</sub>, B = Change in performance from  
408 T<sub>LIM1</sub> and T<sub>LIM2</sub> following NaHCO<sub>3</sub> or Placebo.

409 **Figure 2** Blood acid base balance responses following NaHCO<sub>3</sub> or PLA, where A = pH, B =  
410 blood bicarbonate [HCO<sub>3</sub><sup>-</sup>], and C = blood lactate [BLa<sup>-</sup>]. \* = NaHCO<sub>3</sub> greater than PLA (p  
411 <0.05).

412 **Figure 3** Changes in extracellular electrolytes following NaHCO<sub>3</sub> or PLA, where A = sodium  
413 [Na<sup>+</sup>], B = potassium [K<sup>+</sup>], C = calcium [Ca<sup>2+</sup>], and D = chloride [Cl<sup>-</sup>].

414 **Figure 4** Changes in blood strong ion difference (SID) following NaHCO<sub>3</sub> or PLA. \* =  
415 NaHCO<sub>3</sub> greater than PLA (p <0.05).

416 **Figure 5** Gastrointestinal (GI) discomfort (gut fullness and abdominal discomfort) following  
417 NaHCO<sub>3</sub> or PLA. \* = NaHCO<sub>3</sub> greater than PLA (p <0.05).

418

419 **List of tables**

420 **Table 1** Example of one round of the high intensity interval run (HIIR) protocol. Key: AR\* =  
421 Active recovery; SS\*\* = self-selected during familiarisation

422 **Table 2** Punch combinations sequence utilised during boxing specific performance. Key: MIR:  
423 move in range, MOR: move out of range, J: Jab, BH: backhand, LU: lead uppercut, BU:  
424 backhand uppercut, LH: lead hook, BHH: Backhand hook

425

426 **References**

- 427 Artioli, G. G., Gualano, B., Coelho, D. F., Benatti, F. B., Gailey, A. W., and Lancha Jr, A. H.  
428 (2007). Does sodium-bicarbonate ingestion improve simulated judo performance?. *Int. J.*  
429 *Sport. Nutr. Exerc. Metab.* 17(2), 206-217.
- 430 Atherton, J.C. (2003). Acid-base balance: maintenance of plasma pH. *Anaesth. Intensive. Care.*  
431 4 (12), pp. 419–422.
- 432 Bishop, D., Edge, J., Davis, C., and Goodman, C. (2004). Induced metabolic alkalosis affects  
433 muscle metabolism and repeated-sprint ability. *Med. Sci. Sports. Exerc.* 36(5), 807-813.
- 434 Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Med. Sci. Sports. Exerc.* 14(5),  
435 377-381.
- 436 Bouclin, R., Charbonneau, E., and Renaud, J.M., (1995). Na<sup>+</sup> and K<sup>+</sup> effect on contractility  
437 of frog sartorius muscle: implication for the mechanism of fatigue. *American Journal of*  
438 *Physiology-Cell Physiology.* 268 (6), pp. 1528–1536.
- 439 Cairns, S. P., and Lindinger, M. I. (2008). Do multiple ionic interactions contribute to skeletal  
440 muscle fatigue?. *J. Physiol.* 586(17), 4039-4054.
- 441 Cameron, S. L., McLay-Cooke, R. T., Brown, R. C., Gray, A. R., and Fairbairn, K. A. (2010).  
442 Increased blood pH but not performance with sodium bicarbonate supplementation in elite  
443 rugby union players. *Int. J. Sport. Nutr. Exerc. Metab.* 20(4), 307-321.
- 444 Carr, A. J., Hopkins, W. G., and Gore, C. J. (2011). Effects of acute alkalosis and acidosis on  
445 performance. *Sports. Med.* 41(10), 801-814.
- 446 Cohen, J. (1988). *Statistical power analysis for the behavioural sciences.* L. Erlbaum  
447 Associates.
- 448 Deb, S. K., Gough, L. A., Sparks, S. A., and McNaughton, L. R. (2018). Sodium bicarbonate  
449 supplementation improves severe-intensity intermittent exercise under moderate acute hypoxic  
450 conditions. *Eur. J. Appl. Physiol.* 118(3), 607-615.
- 451 Driller, M. W., Gregory, J. R., Williams, A. D., and Fell, J. W. (2013). The effects of chronic  
452 sodium bicarbonate ingestion and interval training in highly trained rowers. *Int. J. Sport. Nutr.*  
453 *Exerc. Metab.* 23(1), 40-47.
- 454 Edge, J., Bishop, D., and Goodman, C. (2006). The effects of training intensity on muscle  
455 buffer capacity in females. *Eur. J. Appl. Physiol.* 96(1), 97-105.

456 Felipe, L. C., Lopes-Silva, J. P., Bertuzzi, R., McGinley, C., and Lima-Silva, A. E. (2016).  
457 Separate and combined effects of caffeine and sodium-bicarbonate intake on judo performance.  
458 *Int. J. Sports. Physiol. Perform.* 11(2), 221-226.

459 Fitts, R.H. (1994). Cellular mechanisms of muscle fatigue. *Physiological Reviews.* 74 (1), pp. 49–  
460 94.

461 Forbes-Robertson, S., Dudley, E., Vadgama, P., Cook, C., Drawer, S., and Kilduff, L. (2012).  
462 Circadian disruption and remedial interventions. *Sports. Med.* 42(3), 185-208.

463 Gough, L. A., Rimmer, S., Osler, C. J., and Higgins, M. F. (2017). Ingestion of Sodium  
464 Bicarbonate (NaHCO<sub>3</sub>) Following a Fatiguing Bout of Exercise Accelerates Postexercise  
465 Acid-Base Balance Recovery and Improves Subsequent High-Intensity Cycling Time to  
466 Exhaustion. *Int. J. Sport. Nutr. Exerc. Metab.* 27(5), 429-438.

467 Gough, L. A., Brown, D., Deb, S. K., Sparks, S. A., and McNaughton, L. R. (2018a). The  
468 influence of alkalosis on repeated high-intensity exercise performance and acid–base balance  
469 recovery in acute moderate hypoxic conditions. *Eur. J. Appl. Physiol.* 118(12), 2489-2498.

470 Gough, L. A., Deb, S. K., Sparks, S. A., and McNaughton, L. R. (2018b). Sodium bicarbonate  
471 improves 4 km time trial cycling performance when individualised to time to peak blood  
472 bicarbonate in trained male cyclists. *J. Sports. Sci.* 36(15), 1705-1712.

473 Higgins, M.F., James, R.S., and Price, M.J., (2013). The effects of sodium bicarbonate (NaHCO<sub>3</sub>)  
474 ingestion on high intensity cycling capacity. *J. Sports. Sci.* 31 (9), pp. 972–81.

475 Hilton, N. P., Leach, N. K., Sparks, S. A., Gough, L. A., Craig, M. M., Deb, S. K., and  
476 McNaughton, L. R. (2019). A novel ingestion strategy for sodium bicarbonate supplementation  
477 in a delayed-release form: a randomised crossover study in trained males. *Sports medicine-*  
478 *open*, 5(1), 4.

479 Ivarsson, A., Andersen, M. B., Johnson, U., and Lindwall, M. (2013). To adjust or not adjust:  
480 nonparametric effect sizes, confidence intervals, and real-world meaning. *Psychol. Sport.*  
481 *Exerc.* 14(1), 97-102.

482 Jones, R. L., Stellingwerff, T., Artioli, G. G., Saunders, B., Cooper, S., and Sale, C. (2016).  
483 Dose-response of sodium bicarbonate ingestion highlights individuality in time course of blood  
484 analyte responses. *Int. J. Sport. Nutr. Exerc. Metab.* 26(5), 445-453.

485 Lloyd, P., (2004). Strong ion calculator - a practical bedside application of modern quantitative  
486 acid-base physiology. *Crit. Care. Resusc.* 6 (4), pp. 285–94.



487 Lindinger, M. I., and Heigenhauser, G. J. (1991). The roles of ion fluxes in skeletal muscle  
488 fatigue. *Can. J. Physiol. Pharmacol.* 69(2), 246-253.

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

492 McNaughton, L. R., Gough, L., Deb, S., Bentley, D., and Sparks, S. A. (2016). Recent  
493 developments in the use of sodium bicarbonate as an ergogenic aid. *Curr. Sports. Med. Rep.*  
494 15(4), 233-244.

495 Mero, A. A., Hirvonen, P., Saarela, J., Hulmi, J. J., Hoffman, J. R., and Stout, J. R. (2013).  
496 Effect of sodium bicarbonate and beta-alanine supplementation on maximal sprint swimming.  
497 *J. Int. Soc. Sports. Nutr.* 10(1), 52.

498 Messonnier, L., Kristensen, M., Juel, C., and Denis, C. (2007). Importance of pH regulation  
499 and lactate/H<sup>+</sup> transport capacity for work production during supramaximal exercise in  
500 humans. *J. Appl. Physiol.* 102 (5), pp. 1936–44.

501 Morton, J. P., Robertson, C., Sutton, L., and Maclaren, D.P.M. (2010). Making the weight: a  
502 case study from professional boxing. *Int. J. Sport. Nutr. Exerc. Metab.* 20(1), 80-85.

503 de Oliveira, L. F., Saunders, B., & Artioli, G. G. (2018). Is by-passing the stomach a means to  
504 optimise sodium bicarbonate supplementation? a case-study with a post-bariatric surgery  
505 individual. *Int. J. Sport. Nutr. Exerc. Metab.* 1-15.

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

509 Percival, M. E., Martin, B. J., Gillen, J. B., Skelly, L. E., MacInnis, M. J., Green, A. E., ... and  
510 Gibala, M. J. (2015). Sodium bicarbonate ingestion augments the increase in PGC-1 $\alpha$  mRNA  
511 expression during recovery from intense interval exercise in human skeletal muscle. *J. Appl.*  
512 *Physiol.* 119(11), 1303-1312.

513 Pruscino, C. L., Ross, M. L., Gregory, J. R., Savage, B., and Flanagan, T. R. (2008). Effects of  
514 sodium bicarbonate, caffeine, and their combination on repeated 200-m freestyle performance.  
515 *Int. J. Sport. Nutr. Exerc. Metab.* 18(2), 116-130.

516 Saunders, B., Sale, C., Harris, R. C., and Sunderland, C. (2014). Sodium bicarbonate and high-  
517 intensity-cycling capacity: variability in responses. *Int. J. Sports. Physiol. Perform.* 9(4), 627-  
518 632.

519 Siegler, J. C., and Hirscher, K. (2010). Sodium bicarbonate ingestion and boxing performance.  
520 *J. Strength. Cond. Res.* 24(1), 103-108.

521 Siegler, J. C., Marshall, P. W., Finn, H., Cross, R., and Mudie, K. (2018). Acute attenuation of  
522 fatigue after sodium bicarbonate supplementation does not manifest into greater training  
523 adaptations after 10-weeks of resistance training exercise. *PloS one*, 13(5), e0196677.

524 Stephens, T. J., McKenna, M. J., Canny, B. J., Snow, R. J., and McConell, G. K. (2002). Effect  
525 of sodium bicarbonate on muscle metabolism during intense endurance cycling. *Med. Sci.*  
526 *Sports. Exerc.* 34(4), 614-621.

527 Sostaric, S. M., Skinner, S. L., Brown, M. J., Sangkabutra, T., Medved, I., Medley, T., ... and  
528 McKenna, M. J. (2006). Alkalosis increases muscle K<sup>+</sup> release, but lowers plasma [K<sup>+</sup>] and  
529 delays fatigue during dynamic forearm exercise. *J. Physiol.* 570(1), 185-205.

530 Westerblad, H. (2016). Acidosis is not a significant cause of skeletal muscle fatigue. *Med. Sci.*  
531 *Sports. Exerc.* 48(11), 2339-2342.

532 Zabala, M., Requena, B., Sánchez-Muñoz, C., González-Badillo, J. J., García, I., Ööpik, V.,  
533 and Pääsuke, M. (2008). Effects of sodium bicarbonate ingestion on performance and  
534 perceptual responses in a laboratory-simulated BMX cycling qualification series. *J. Strength.*  
535 *Cond. Res.* 22(5), 1645-1653.

536 Zabala, M., Peinado, A. B., Calderón, F. J., Sampedro, J., Castillo, M. J., and Benito, P. J.  
537 (2011). Bicarbonate ingestion has no ergogenic effect on consecutive all out sprint tests in  
538 BMX elite cyclists. *Eur. J. Appl. Physiol.* 111(12), 3127-3134.

539

540

541

542

543

544

545 **Table 1**

<b>Exercise duration (sec)</b>	<b>~%<math>\dot{V}O_{2PEAK}</math></b>	<b>Intensity level</b>
30	90	High
30	75	Moderate
30	90	High
30	75	Moderate
30	90	High
30	75	Moderate
30	90	High
30	75	Moderate
60 AR*	SS**	Low

Key: AR\* = Active recovery; SS\*\* = self-selected during familiarisation

546

547

548

549

550

551

552

553

554

555

556

557 **Table 2**

<b>Phase 1</b>	<b>Phase 2 (combinations)</b>	<b>Phase 3</b>
MIR	J-	MOR
MIR	J-BH	MOR
MIR	J-BH-LU	MOR
MIR	J-BH-LU-BU	MOR
MIR	J-BH-LU-BU-LH	MOR
MIR	J-BH-LU-BU-LH- BHH	MOR

Key: MIR: move in range, MOR: move out of range, J: Jab, BH: backhand, LU: lead uppercut, BU: backhand uppercut, LH: lead hook, BHH: Backhand hook

558