

TITLE PAGE

Sodium bicarbonate supplementation delays neuromuscular fatigue without changes in

Authors

Paul Ansdell^{1,2}, Jeanne Dekerle¹

¹ Sport, Exercise Science And Medicine (SESAME), University of Brighton, Eastbourne, United Kingdom.

² Faculty of Health and Life Sciences, Department of Sport, Exercise & Rehabilitation, Northumbria University, Newcastle, United Kingdom

Address for correspondence:

Paul Ansdell

Faculty of Health and Life Sciences

Department of Sport, Exercise & Rehabilitation

Northumbria University

Newcastle upon Tyne

NE1 8ST

performance outcomes during a basketball match simulation protocol

UK

Email : paul.ansdell@northumbria.ac.uk

Phone: +44 (0)191 243 7018

Fax: +44 (0)191 227 4713

Disclosure statement of funding received for this work: none

Conflict of interest: none

1 **ABSTRACT**

2 **Purpose:** To investigate the development of neuromuscular fatigue during a basketball game
3 simulation and ascertain whether sodium bicarbonate (NaHCO₃) supplementation attenuates
4 any neuromuscular fatigue that persists. **Methods:** Ten participants ingested 0.2 g.kg⁻¹ of
5 NaHCO₃ (or an equimolar placebo dosage of sodium chloride [NaCl]) 90 and 60 minutes prior
6 to commencing a basketball game simulation (ALK-T vs PLA-T). Isometric maximal voluntary
7 contractions of the knee extensors (MVIC) and potentiated high (100 Hz) and low (10 Hz)
8 frequency doublet twitches were recorded before and after each match quarter for both trials.
9 In addition, 15 m sprint times and layup completion (%) were recorded during each quarter.
10 **Results:** MVIC, 100 and 10 Hz twitch forces declined progressively in both trials ($P<0.05$)
11 with a less pronounced decrease in MVIC during ALK-T ($P<0.01$). Both 100 and 10 Hz twitch
12 forces were also significantly greater in ALK-T ($P<0.05$). 15 m sprint time increased over the
13 course of both trials (~2%, $P<0.01$); however, no significant condition or time effect was found
14 for layup completion ($P>0.05$). **Conclusion:** A basketball simulation protocol induces a
15 substantial amount of neuromuscular (reduction in knee extensor MVICs) and peripheral
16 fatigue with a concomitant increase in 15 m sprint time over the protocol. NaHCO₃
17 supplementation attenuated the rate of fatigue development by protecting contractile elements
18 of the muscle fibres. **Practical Applications:** This study provides coaches with information
19 about the magnitude of fatigue induced by a simulated basketball game, and provides evidence
20 of the efficacy of NaHCO₃ in attenuating fatigue.

21

22 **KEY WORDS**

23 Alkalosis; muscular fatigue; peripheral fatigue; team sports

24

25 INTRODUCTION

26 Basketball matches are characterised by a large volume of short duration, high intensity
27 movements as shown via time-motion analysis (25). Simulated games can also raise mean
28 oxygen uptake ($\dot{V}O_2$) and heart rate (HR) values to approximately 65% and 85% of their
29 maximum, respectively (25, 28). Due to the elevated metabolic demand of a basketball game,
30 a build-up of deleterious metabolites (i.e. H^+ , Pi) may reduce force producing capacity of the
31 working muscles (2). This is deemed neuromuscular fatigue, and is defined in the present work
32 as any transient, exercise-induced reduction in muscular force generating capacity (42), with
33 underpinning mechanisms of peripheral or central origins. Previous research has shown that
34 explosive power and sprint ability is reduced following basketball-related activity (9).
35 However, to our knowledge, no study has yet investigated the time course of various sites of
36 neuromuscular fatigue during a simulated basketball match, and the efficacy of a potentially
37 ergogenic supplement in ameliorating the aforementioned fatigue by reducing metabolite
38 accumulation.

39
40 As a result of high intensity exercise (such as basketball), extra and intra-cellular ionic
41 concentrations are altered within the muscles, causing reduced contractile performance. For a
42 complete review of the processes contributing to peripheral fatigue see Allen et al (2). Examples
43 of factors involved in impairment within the muscular contractile apparatus are reduced
44 intracellular potassium ion (K^+) concentrations caused by efflux into the interstitial spaces,
45 resulting in extracellular accumulation (19). This negatively affects the capacity of the
46 sarcolemma to propagate action potentials (27). This potentially occurs as Na^+ , K^+ ATPase
47 activity is inhibited by the increased presence of hydrogen ions (H^+) (acidosis).

48 Similarly, acidosis inhibits myofibril ATPase activity, leading to reduced calcium ion (Ca^{2+})
49 reuptake to the sarcoplasmic reticulum (SR) and consequently less Ca^{2+} released from the SR
50 when prompted by an action potential (7, 22).

51

52 In this study, contractile function was measured using potentiated, electrically-evoked paired
53 twitches at two different frequencies (10 and 100 Hz) in an attempt to refine the sites of
54 peripheral fatigue development. The mechanical response (twitch) to low frequency doublets
55 (10 Hz) has been shown to be modulated by the extent of Ca^{2+} release from the SR (19, 21).
56 High frequency doublets (100 Hz), and their respective twitch amplitude, have been shown not
57 to be affected by moderate decreases in Ca^{2+} . Therefore decreases in high frequency twitch
58 amplitude reflect attenuated action potential propagation caused by extracellular K^+
59 accumulation (21). The ratio of low:high frequency twitch forces gives detail about the
60 aetiology of contractile decline during a fatiguing task (27).

61

62 The role acidosis plays in the development of neuromuscular fatigue during high intensity
63 exercise (such as basketball) remains under debate (10, 44). However, it is generally agreed
64 that athletes who perform high intensity exercise (such as basketball players) would likely
65 benefit from NaHCO_3 supplementation (8) as it attenuates the aforementioned negative effects
66 of acidosis. For instance, a reduction in extracellular accumulation of K^+ during exhaustive
67 exercise has been evidenced following NaHCO_3 supplementation (40). NaHCO_3
68 supplementation also attenuates the inhibiting effects of H^+ by increasing the intra –
69 extracellular pH gradient. This allows for greater efflux of deleterious metabolites outside the
70 muscle cells and attenuates their harmful effects on the contractile function (26).

71

72 NaHCO₃ has been shown to enhance high-intensity performance (5, 6) and delay the
73 development of neuromuscular fatigue during a fatiguing task (38). The ergogenic effects found
74 in the aforementioned laboratory-based studies give rationale for the investigation of NaHCO₃
75 as an ergogenic aid during high-intensity team sport activity such as basketball. Interestingly,
76 only a limited amount of studies have investigated the effect of NaHCO₃ supplementation on
77 performance outcomes during simulated game based protocols (1, 23, 31, 34), and
78 neuromuscular function has never been assessed throughout a simulated basketball match.
79 Afman et al (1) recently found a beneficial effect of NaHCO₃ supplementation on 15m sprint
80 times, but not layup completions, during a modified Loughborough Intermittent Sprint Test
81 (LIST), which was validated to replicate the demands of a 40-min basketball game. Therefore,
82 the present study aims to investigate the development of neuromuscular fatigue and more
83 specifically, the peripheral mechanisms during a basketball game simulation. The study also
84 aims to ascertain whether NaHCO₃ supplementation attenuates this development. It was
85 hypothesised that there would be a significant decline in both voluntary force generating
86 capacity of the knee extensors and the amplitude of evoked paired-twitches. It was hypothesised
87 that this decrease in contractile function would lead to faster 15-m sprint times throughout the
88 protocol and with smaller declines in the supplement (ALK-T) compared to the placebo (PLA-
89 T) trial.

90

91 **METHODS**

92 *Experimental Approach to the Problem*

93 Participants visited the laboratories on three separate occasions. Three and seven days separated
94 familiarisation and 1st fatiguing trial, and 1st and 2nd fatiguing trials respectively, to ensure full
95 washout of the supplement/placebo (5). Familiarisation involved a neuromuscular function

96 assessment performed on an isokinetic dynamometer, followed by one block of the modified
97 LIST protocol. For the two experimental trials, participants performed four blocks of the
98 modified LIST with neuromuscular assessment prior to, and following each block of the LIST
99 (1). Participants were asked to avoid consuming any stimulants or alcohol, and to replicate food
100 intake during a 24-hour period before testing. The study was a double-blind
crossover design with exposure to supplements randomized and counterbalanced. Each
participant received extensive information, and signed an informed consent form and medical
questionnaire after they had the opportunity to ask any questions to researchers. The protocol
was approved by the University Ethics committee and adhered to the Declaration of Helsinki.

Subjects

Ten healthy and active male basketball players volunteered to take part in the study (age 21 ± 1 years; height: 182 ± 5 cm; weight: 81.5 ± 8 kg). All participants had over 4 years of competitive basketball experience.

Procedures

Neuromuscular Function Assessment

For the neuromuscular assessment of the right knee extensors, participants sat on the Con-Trex Multi-Joint system (Con-Trex, Dubendorf, Switzerland) as per the published reliability study (30) (~85° hip angle; distal dynamometer's shin pad attached 2–3 cm proximal to the
101 lateral malleolus with a strap around the shank; straps were fastened and locked across chest
102 and pelvis; movement resisting pad over the mid-thigh of the contracting leg). Knee angle was
103 kept at 90° for all maximal voluntary isometric contractions (MVICs) and twitches.
104

105 Torque measurement was corrected to take gravity effect into account. Participants were
106 instructed to cross their arms across their chest and were provided with visual feedback of force
107 during the protocol.

108 A 48 mm² self-adhesive cathode electrode (CF3200, Nidd Valley Medical Ltd, Harrogate, UK)
109 was placed directly over the femoral nerve in the femoral triangle with the anode placed directly
110 onto the greater trochanter of the femur (Prottens, Bio Protech Inc, Korea).

111 Percutaneous electrical stimulation was delivered by a constant-current stimulator (DS7A,
112 Digitimer, Letchworth Garden City, Great Britain). Stimulations were triggered manually using
113 a PowerLab 15T (Model ML818, AdInstruments Pty Ltd, Dunedin, New Zealand) and force
114 production was recorded using LabChart 7 software (AdInstruments Pty Ltd, Dunedin,
115 New Zealand). Sprint times (15-m) were recorded using wireless electronic timing gates (TC
116 Timing System, Brower, Utah, USA). Participants began each sprint from a standing start 10cm
117 behind the timing gates (see figure 1).

118 *Familiarisation Session*

119 Single electrical 200 μ s impulses were delivered to the right femoral nerve via the surface
120 electrode. Percutaneous single stimuli were delivered at 10 mA increasing by 10mA until a
121 plateau in twitch force amplitude was reached. This intensity was increased to 130%, to ensure
122 supramaximal stimulations were delivered (mean intensity: 170 \pm 35 mA). This process was
123 repeated before each experimental visit. The MVIC familiarisation protocol then consisted of
124 2 and then 3 \times 5-s voluntary contractions performed at 50% and 75% of maximal subjective
125 effort, respectively. The participants then performed 3 \times 5-s MVICs. Each maximal contraction
126 was followed by two doublet stimulations (100 Hz and 10 Hz) in 1-s
127 intervals.

128

129

130 *Experimental Protocol*

131 Neuromuscular baseline tests were performed followed by a short standardised warm up (a
132 4length jog of the basketball court). After baseline and warm ups, participants completed four
133 blocks of 11 repetitions of the modified LIST shown in figure 1 (1), meaning 11 sprints and
layups were performed per quarter. Participants had 5 minutes rest between quarters, in
which neuromuscular fatigue assessment was performed. Three 5 s MVICs with 60 s rest
between were performed with two doublet stimulation s (10 Hz and 100 Hz) following the
contractions in 1 s intervals. Due to the time taken to move from basketball court to the
dynamometer following each quarter, the timing of the first MVIC was standardised to 75 s.

FIGURE 1 HERE

Supplement

Participants arrived 90 minutes prior to commencement of the protocol in order to consume
the first half of either the supplement or placebo; NaHCO_3 was delivered in two separate
dosages of 0.2 g.kg⁻¹ with the second dosage consumed 60 minutes prior. NaHCO_3 was
dissolved in 500 ml of non-calorie-free cordial each, totalling 0.4 g.kg⁻¹. Sodium
chloride (placebo) was composed of two 0.138 g.kg⁻¹ dosages dissolved in 500 ml water and
cordial each (equimolar amount of sodium to account for alterations in Na^+ handling; for
134 more details, see (20)). The same amount of supplement/placebo was consumed 60 minutes
135 prior to exercise. A similar ingestion protocol has been shown to benefit prolonged intermittent
136 activity with no reported incidences of gastrointestinal disturbances following NaHCO_3
137 supplementation, as did the present study (5).

138

139 *Data Analysis*

140 The maximum 500-ms value was recorded as maximal force for each MVIC plateau, and the
141 peak twitch amplitude was computed for each doublet stimulation. The greatest value over each
142 set of three MVICs and twitches was subsequently recorded for each time point.

143 Coefficient of variations between the 3 measures were $2.6 \pm 2.0\%$ for MVIC, $3.5 \pm 2.7\%$ for
144 100 Hz twitch, and $3.0 \pm 2.2\%$ for 10 Hz twitch. Each 15 m sprint time was recorded in seconds
145 (s). Successful completions for the layups were expressed as a percentage of total number of
146 attempts per quarter (out of 11).

147 *Statistical Analysis*

148 Normal distributions were verified (Kolmogorov-Smirnov test) and one-way (1 x 5) repeated
149 measures ANOVAs were run to assess the change in neuromuscular variables (MVC, 100Hz ,
150 10 Hz twitches) and quantify the magnitude of fatigue elicited over the course of the placebo
151 trial (Baseline, Q1, Q2, Q3, Q4). A two-way (2 x 5) repeated measures ANOVAs was
152 performed to test for between condition (ALK-T vs PLA-T) and time differences (Baseline,
153 Q1, Q2, Q3, Q4). If sphericity assumption was violated (Mauchly's test) then Fratio's were
154 adjusted according to the Greenhouse-Geisser procedure. Significant effects of ANOVAs were
155 followed up using the Bonferroni-corrected pairwise post hoc test.

156 Significance was accepted at $P \leq 0.05$ and all data is presented as mean \pm standard deviation
157 (SD). All statistical analyses were performed using SPSS (version 20, Chicago, USA).

158

159

160

161

162

163 **RESULTS**

164 TABLE 1 HERE

165 FIGURE 2 HERE

166

167 MVIC force ($F_{(4,36)} = 42.0, P < 0.01$), decreased significantly over time but with no
168 significant difference between conditions ($P > 0.05$) (Table 1 and Figure 2). The loss of
169 MVIC was less pronounced during ALK-T as shown by the significant time \times condition
170 interaction ($F_{(4,36)} = 6.88, P < 0.01$). However, post-hoc tests did not reveal a significant
171 difference between trials at any time points ($P > 0.05$). The one way ANOVA showed that
172 during PLA-T, the decrement in MVIC ($F_{(4,36)} = 36.9, P < 0.01$) was progressive from
173 baseline to the 3rd quarter ($P < 0.05$), with a plateau occurring thereafter ($P > 0.05$).

174

175 100 Hz twitch ($F_{(4,36)} = 20.25, P < 0.01$) and 10 Hz twitch ($F_{(4,36)} = 24.3, P < 0.01$) also
176 decreased significantly over time. No time \times condition interaction effect was found for either
177 evoked twitches (100 Hz: $F_{(4,36)} = 0.76, P = 0.56$; 10 Hz: $F_{(4,36)} = 1.30, P = 0.29$). 100 Hz and
178 10 Hz evoked twitch forces were both greater throughout the protocol in ALK-T (condition
179 effect: 100 Hz: $F_{(1,9)} = 11.8, P < 0.01$; 10 Hz: $F_{(1,9)} = 8.77, P < 0.05$). The one way ANOVA
180 showed that during PLA-T, 100 and 10 Hz twitches were not different from baseline ($P >$
181 0.05) until after the second quarter from which time point a reduction was significant ($P <$
182 0.05). No time or condition effect was observed for 10:100 Hz twitches ratio ($P > 0.05$).

183

184 No condition or interaction effect were found for either of the performance variables ($P >$
185 0.05) but the 15-m sprint times became significantly slower over both trials (time effect: $F_{(3,27)}$
186 $= 9.39, P < 0.01$). The participants' sprints in both trials were systematically slower from one

187 quarter to the next ($P < 0.05$, Table 1). When comparing first vs last quarter sprint times, both
188 ALK-T and PLA-T were significantly longer (ALK-T: -1.7%, $F_{(3,7)} = 4.3$, $P <$
189 0.01; PLA-T -2.4%, $F_{(3,7)} = 9.3$, $P < 0.05$).

190

191 **DISCUSSION**

192 To our knowledge this is the first study reporting development of neuromuscular fatigue during
193 simulation of a basketball match. Maximal force production of the knee extensors (MVIC)
194 during PLA-T reduced throughout the first three quarters of the simulated match
195 (Figure 2; Table 1; ~5% loss per quarter) with no further reduction in the final quarter.
196 Peripheral fatigue was evident from the 2nd quarter of the protocol with disturbances of
197 contractile properties. The ~15% reduction in MVIC torque recorded post 3rd and 4th quarter in
198 this study is similar to the ~15% reduction reported after a 60-min squash match (12), and
199 within the ~11% (11, 13, 29) to ~20% range (16, 17) reported for laboratory based studies
200 investigating repeated sprint activity (4-to 10-s sprints, 8-12 repetitions, 10- to 30-s passive
201 recovery).

202

203 To our knowledge, this is also the first study applying femoral nerve stimulations to assess
204 mechanisms of peripheral fatigue during a basketball game simulation. The ~15% reductions
205 in evoked twitch forces from baseline for both doublet stimulations are similar to those
206 previously reported in laboratory-based studies following repeated sprint exercise (9-15%; (29,
207 32)). In the present study, changes in the several mechanisms of contractile function
208 impairment seem to adopt a similar time course with a decrease after the 2nd quarter, and no
209 further decrease thereafter (apart from one occurrence: 10 Hz twitch between quarter 2 and 3,
210 $P = 0.01$). Perrey et al (29) found decreases of 15% in low frequency (20 Hz) twitch forces but

211 of only 8% in the high frequency (80 Hz) twitch forces following repeated sprints. Their
212 decreased ratio of low:high frequency evoked twitches (-9%) suggested that muscle fibre
213 excitability was the predominant cause for the impairment of the contractile function. In
214 contrast, the present study found decreases of similar extent in low and high frequency evoked
215 twitch forces, suggesting that a basketball simulation protocol affects both excitation and
216 contraction mechanisms to a similar degree.

217

218 15-m sprint times increased by ~2% in PLA-T following the basketball simulation protocol,
219 compared to Afman et al (1) who reported a ~5% increase during the placebo trial of the
220 modified LIST. This lies within the 2-10% decrease in sprint times of short distances (≤ 20 m)
221 typically reported for team sport activities (3, 4, 18, 24). These reductions in running
222 performance are greater than losses in 'pure' strength measurements such as MVICs mentioned
223 earlier (~10-20%). This could be explained by a possible change in sprint mechanics in a
224 fatigued state, affecting speed production as a consequence (33). For instance, in the present
225 study, participants were tightly secured on the dynamometer to avoid any extra bodily
226 movements other than the knee extensors, so that MVIC forces could not be affected by a
227 change in technique. Interestingly however, both evoked twitches were significantly greater in
228 ALK-T, demonstrating the protective effect increased extracellular buffering agents have on
229 both potassium and calcium ion-related contractile properties of the muscle fibres of the knee
230 extensors. This protection of the muscle force-generating capacity is further illustrated in the
231 present study by the attenuation in the continuous development of
232 neuromuscular fatigue (MVIC torque) during the protocol under the NaHCO_3
233 supplementation.

234

235 Several studies have to date reported the effect of NaHCO₃ on neuromuscular fatigue. This was
236 following submaximal isometric calf muscles contractions (36), a 2-min voluntary knee
237 extension (35), tetanic stimulation (39), and high-intensity repeated sprint cycling (38). In
238 agreement with our findings, all found no condition effect on MVIC forces from pre- to
239 postexercise. In contrast with the present results however, the force decline was similar in both
240 alkalosis and placebo trials (35). The differences in the fatiguing protocols and measurement
241 methods might explain these discrepancies. Our basketball simulation protocol engaged a
242 greater muscle mass and was of longer duration so that a time × condition interaction effect
243 was more likely to occur. Stimulations were applied to the posterior tibial nerve to evoke force
244 in the calf muscles in Siegler et al (36), and as suggested by the authors themselves, the
245 relatively low task demand coupled with the small muscle group might have contributed to the
246 lack of pH effect.

247

248 The 15-m sprint times were on average 0.2% faster, and MVIC torque 3.3% greater in ALKT
249 (5 measures, *n* = 10). Whilst 7 out of 10 participants recorded lesser decreases in 100 and 10
250 Hz twitch amplitudes in ALK-T compared to PLA-T, the two-way ANOVA did not depict any
251 interaction effect. A meta-analysis reported for an ergogenic effect of only 1.7% on some
252 performance indicators such as mean power during repeated sprint exercise (8). Several studies
253 also reported a lack of condition effect on 15-m sprint times following ingestion of a buffering
254 agent compared to a placebo (1, 34). Whilst the present study focussed on mechanisms affecting
255 the contractile apparatus, it should be noted that alterations within the CNS may also be
256 responsible for declines in voluntary force. Team sport activity has been shown to induce
257 substantial decreases in voluntary activation of quadriceps muscles(14, 43). NaHCO₃ may also
258 attenuate afferent feedback associated with metabolite accumulation (37).

259 Therefore, the ergogenic effects demonstrated in the present study (i.e. attenuated MVIC force
260 reduction) might not be purely due to protection of contractile mechanisms. Furthermore,
261 NaHCO₃ supplementation in the present study was limited by the absence of blood gas
262 measurements; however there is evidence that a similar supplementation protocol to the one
263 used in this study raises [HCO₃⁻] levels by ~5mmol.L⁻¹ and sustains elevated blood pH and
264 HCO₃⁻ during a prolonged intermittent sprint protocol ENREF_17(5). Factors such as time to
265 peak [HCO₃⁻] and [pH] also show high degrees of inter and intra-individual variability (15, 41).
266 Therefore, it is possible that the ergogenic effect seen in the present study may not have been
267 maximal as the ingestion times were standardised to 90 and 60 minutes.

268 In conclusion, the present study shows a two-phase response in the development of fatigue over
269 time during a simulated basketball match, with an initial early development of neuromuscular
270 and peripheral fatigue after just two quarters of simulated match. Beyond which no further
271 deleterious effect on the neuromuscular function can be seen. This occurred alongside a
272 slowing down of 15-m sprint times while layup scores remained unchanged. The second major
273 finding is that ingestion of sodium bicarbonate 90 and 60 minutes priorexercise attenuates the
274 above-mentioned development of neuromuscular fatigue. Maximal force production can be
275 preserved until the 3rd quarter of the match. The supplementation preserved both potassium and
276 calcium ion-related contractile properties of the knee extensors so that a greater muscular force
277 generating capacity was possible in the alkaline condition when twitches were evoked using
278 paired stimulations of the femoral nerve. This could be the reason maximal force production
279 was preserved during the protocol.

280

281 The present findings should be interpreted with caution due to a small sample size weakening
282 overall statistical power. For example, there was a condition effect for MVIC torque alongside

283 a condition \times time interaction effect, but with no post-hoc difference depicted. This is not
284 uncommon in the literature surrounding NaHCO_3 supplementation (36, 38). Another limitation
285 in this study refers to the lack of electromyography (EMG) measurements. The intensity for
286 electrical stimulation was therefore based on a plateau of twitch force with increasing current,
287 rather than based on a plateau identified for the compound muscle action potential (M wave).
288 As a result, there is no absolute confidence that all motor units were
innervated by the electrical stimulation. However, the mean intensity in the present study
(170 mA) is comparable to that of studies using plateaus in twitch and M-wave amplitudes
for the determination of stimulation threshold in the knee extensors in similar population
(80-170 mA,(12); ~190 mA, (14)).

PRACTICAL APPLICATIONS

A simulated basketball match protocol causes a significant amount of overall and peripheral
fatigue from the 1st and 2nd quarter, respectively, as quantified by neuromuscular assessments.
Sprint times are also slower throughout simulated basketball match. The employment of
intelligent substitution timings and tactics should be used to negate this effect.

Supplementing two dosages of $0.3 \text{ g}\cdot\text{kg}^{-1} \text{NaHCO}_3$ 90 and 60 minutes prior to a basketball
simulated match protocol can significantly delay the rate of development of neuromuscular
fatigue by protecting contractile properties of muscle fibres.

Acknowledgements

289
290 This research has not received any external financial support. The results of the present study
291 do not constitute endorsement of the product by the authors or the NSCA.

292

293

294

295 **References**

- 296 1. Afman G, Garside RM, Dinan N, Gant N, Betts JA, and Williams C. Effect of
297 carbohydrate or sodium bicarbonate ingestion on performance during a validated
298 basketball simulation test. *Int J Sport Nutr Exerc Metab* 24: 632-644, 2014.
- 299 2. Allen DG, Lamb GD, and Westerblad H. Skeletal muscle fatigue: cellular mechanisms.
300 *Physiol Rev* 88: 287-332, 2008.
- 301 3. Andersson H, Raastad T, Nilsson J, Paulsen G, Garthe I, and Kadi F. Neuromuscular
302 fatigue and recovery in elite female soccer: effects of active recovery. *Med Sci Sports
303 Exerc* 40: 372-380, 2008.
- 304 4. Ascensao A, Rebelo A, Oliveira E, Marques F, Pereira L, and Magalhaes J. Biochemical
305 impact of a soccer match - analysis of oxidative stress and muscle damage markers
306 throughout recovery. *Clinical biochemistry* 41: 841-851, 2008.
- 307 5. Bishop D and Claudius B. Effects of Induced Metabolic Alkalosis on Prolonged
308 Intermittent-Sprint Performance. *Medicine & Science in Sports & Exercise* 37: 759767,
309 2005.
- 310 6. Bishop D, Edge J, Davis C, and Goodman C. Induced metabolic alkalosis affects muscle
311 metabolism and repeated-sprint ability. *Med Sci Sports Exerc* 36, 2004.
- 312 7. Bruton JD, LÄNnergren J, and Westerblad H. Mechanisms underlying the slow
313 recovery of force after fatigue: importance of intracellular calcium. *Acta Physiologica
314 Scandinavica* 162: 285-293, 1998.
- 315 8. Carr AJ, Hopkins WG, and Gore CJ. Effects of Acute Alkalosis and Acidosis on
316 Performance. *Sports Medicine* 41: 801-814, 2011.
- 317 9. Castagna C, Impellizzeri FM, Rampinini E, D'Ottavio S, and Manzi V. The Yo-Yo
318 intermittent recovery test in basketball players. *Journal of Science and Medicine in
319 Sport* 11: 202-208, 2008.
- 320 10. Fitts RH. The Role of Acidosis in Fatigue: Pro Perspective. *Med Sci Sports Exerc* 48:
321 2335-2338, 2016.
- 322 11. Girard O, Bishop DJ, and Racinais S. Hot conditions improve power output during
323 repeated cycling sprints without modifying neuromuscular fatigue characteristics. *Eur
324 J Appl Physiol* 113: 359-369, 2013.
- 325 12. Girard O, Micallef J-P, Noual J, and Millet GP. Alteration of neuromuscular function
326 in squash. *Journal of Science and Medicine in Sport* 13: 172-177, 2010.
- 327 13. Goodall S, Charlton K, Howatson G, and Thomas K. Neuromuscular fatigability during
328 repeated-sprint exercise in male athletes. *Med Sci Sports Exerc* 47: 528-536, 2015.
- 329 14. Goodall S, Thomas K, Harper LD, Hunter R, Parker P, Stevenson E, West D, Russell
330 M, and Howatson G. The assessment of neuromuscular fatigue during 120 min of
331 simulated soccer exercise. *Eur J Appl Physiol* 117: 687-697, 2017.

- 332 15. Gough LA, Deb SK, Sparks AS, and McNaughton LR. The Reproducibility of Blood
333 Acid Base Responses in Male Collegiate Athletes Following Individualised Doses of
334 Sodium Bicarbonate: A Randomised Controlled Crossover Study. *Sports Medicine*:
335 111, 2017.
- 336 16. Hureau TJ, Ducrocq GP, and Blain GM. Peripheral and Central Fatigue Development
337 during All-Out Repeated Cycling Sprints. *Med Sci Sports Exerc* 48: 391-401, 2016.
- 338 17. Hureau TJ, Olivier N, Millet GY, Meste O, and Blain GM. Exercise performance is
339 regulated during repeated sprints to limit the development of peripheral fatigue beyond
340 a critical threshold. *Experimental Physiology* 99: 951-963, 2014.
- 341 18. Ispirlidis I, Fatouros IG, Jamurtas AZ, Nikolaidis MG, Michailidis I, Douroudos I,
342 Margonis K, Chatzinikolaou A, Kalistratos E, Katrabasas I, Alexiou V, and Taxildaris
343 K. Time-course of changes in inflammatory and performance responses following a
344 soccer game. *Clinical journal of sport medicine : official journal of the Canadian
345 Academy of Sport Medicine* 18: 423-431, 2008.
- 346 19. Jones DA. High- and low-frequency fatigue revisited. *Acta Physiologica Scandinavica*
347 156: 265-270, 1996.
- 348 20. Juel C. Muscle pH regulation: role of training. *Acta Physiologica Scandinavica* 162:
349 359-366, 1998.
- 350 21. Keeton RB and Binder-Macleod SA. Low-Frequency Fatigue. *Physical Therapy* 86:
351 1146-1150, 2006.
- 352 22. Kent-Braun AJ. Central and peripheral contributions to muscle fatigue in humans
353 during sustained maximal effort. *Eur J Appl Physiol Occup Physiol* 80: 57-63, 1999.
- 354 23. Krstrup P, Ermidis G, and Mohr M. Sodium bicarbonate intake improves highintensity
355 intermittent exercise performance in trained young men. *Journal of the International
356 Society of Sports Nutrition* 12: 1-7, 2015.
- 357 24. Magalhães J, Rebelo A, Oliveira E, Silva JR, Marques F, and Ascensão A. Impact of
358 Loughborough Intermittent Shuttle Test versus soccer match on physiological,
359 biochemical and neuromuscular parameters. *European journal of applied physiology*
360 108: 39, 2009.
- 361 25. McInnes SE, Carlson JS, Jones CJ, and McKenna MJ. The physiological load imposed
362 on basketball players during competition. *Journal of Sports Sciences* 13: 387-397, 1995.
- 363 26. McNaughton LR, Siegler J, and Midgley A. Ergogenic Effects of Sodium
364 Bicarbonate. *Current Sports Medicine Reports* 7: 230-236, 2008.
- 365 27. Millet GY, Martin V, Martin A, and Vergès S. Electrical stimulation for testing
366 neuromuscular function: from sport to pathology. *Eur J Appl Physiol* 111: 2489-2500,
367 2011.
- 368 28. Narazaki K, Berg K, Stergiou N, and Chen B. Physiological demands of competitive
369 basketball. *Scand J Med Sci Sports* 19: 425-432, 2009.
- 370 29. Perrey S, Racinais S, Saimouaa K, and Girard O. Neural and muscular adjustments
371 following repeated running sprints. *Eur J Appl Physiol* 109: 1027-1036, 2010.

- 372 30. Place N, Maffiuletti NA, Martin A, and Lepers R. Assessment of the reliability of
373 central and peripheral fatigue after sustained maximal voluntary contraction of the
374 quadriceps muscle. *Muscle Nerve* 35: 486-495, 2007.
- 375 31. Price M, Moss P, and Rance S. Effects of sodium bicarbonate ingestion on prolonged
376 intermittent exercise. *Med Sci Sports Exerc* 35: 1303-1308, 2003.
- 377 32. Racinais S, Girard O, Micallef JP, and Perrey S. Failed Excitability of Spinal
378 Motoneurons Induced by Prolonged Running Exercise. *Journal of Neurophysiology* 97:
379 596-603, 2007.
- 380 33. Ratel S, Williams CA, Oliver J, and Armstrong N. Effects of Age and Recovery
381 Duration on Performance During Multiple Treadmill Sprints. *Int J Sports Med* 27: 18,
382 2006.
- 383 34. Saunders B, Sale C, Harris RC, and Sunderland C. Effect of sodium bicarbonate and
384 Beta-alanine on repeated sprints during intermittent exercise performed in hypoxia. *Int*
385 *J Sport Nutr Exerc Metab* 24: 196-205, 2014.
- 386 35. Siegler JC and Marshall P. The effect of metabolic alkalosis on central and peripheral
387 mechanisms associated with exercise-induced muscle fatigue in humans. *Experimental*
388 *physiology* 100: 519-530, 2015.
- 389 36. Siegler JC, Marshall P, Pouslen MK, Nielsen N-PB, Kennedy D, and Green S. The
390 effect of pH on fatigue during submaximal isometric contractions of the human calf
391 muscle. *Eur J Appl Physiol* 115: 565-577, 2015.
- 392 37. Siegler JC, Marshall PW, Bishop D, Shaw G, and Green S. Mechanistic Insights into
393 the Efficacy of Sodium Bicarbonate Supplementation to Improve Athletic Performance.
394 *Sports Med Open* 2: 11, 2016.
- 395 38. Siegler JC, Marshall PWM, Raftroy S, Brooks C, Dowswell B, Romero R, and Green S.
396 The differential effect of metabolic alkalosis on maximum force and rate of force
397 development during repeated, high-intensity cycling. *J Appl Physiol (1985)* 115: 1634-
398 1640, 2013.
- 399 39. Siegler JC, Mudie K, and Marshall P. The influence of sodium bicarbonate on maximal
400 force and rates of force development in the triceps surae and brachii during fatiguing
401 exercise. *Experimental physiology* 101: 1383-1391, 2016.
- 402 40. Sostaric SM, Skinner SL, Brown MJ, Sangkabutra T, Medved I, Medley T, Selig SE,
403 Fairweather I, Rutar D, and McKenna MJ. Alkalosis increases muscle K⁺ release, but
404 lowers plasma [K⁺] and delays fatigue during dynamic forearm exercise. *The Journal*
405 *of physiology* 570: 185-205, 2006.
- 406 41. Sparks A, Williams E, Robinson A, Miller P, Bentley DJ, Bridge C, and Mc Naughton
407 LR. Sodium bicarbonate ingestion and individual variability in time-topeak pH.
408 *Research in Sports Medicine* 25: 58-66, 2017.
- 409 42. Taylor JL and Gandevia SC. A comparison of central aspects of fatigue in submaximal
410 and maximal voluntary contractions. *J Appl Physiol (1985)* 104: 542550, 2008.
- 411 43. Thomas K, Dent J, Howatson G, and Goodall S. Etiology and Recovery of
412 Neuromuscular Fatigue following Simulated Soccer Match-Play. *Medicine & Science*
413 *in Sports & Exercise* In Press, 2017.
- 414 44. Westerblad H. Acidosis Is Not a Significant Cause of Skeletal Muscle Fatigue. *Med Sci*
415 *Sports Exerc* 48: 2339-2342, 2016.

416

417 **Figure Legends:**

418 Figure 1: Schematic of one quarter of the modified Loughborough Intermittent Sprint Test
419 (LIST).

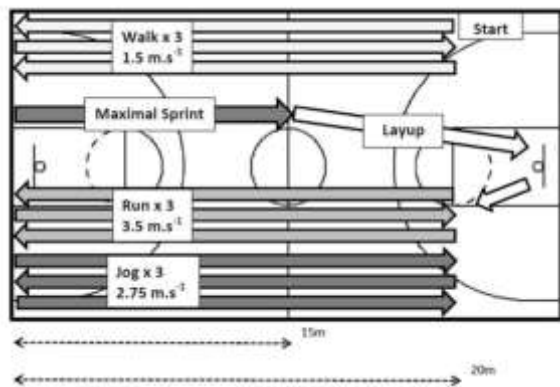
Figure 2: Neuromuscular function assessment by playing quarter. Data presented in mean
SD. A: MVIC force throughout the protocol; B: 100 Hz twitch force; C: 10 Hz twitch force.
Significant group effect; \$ Significant time effect; *Significant interaction effect

420

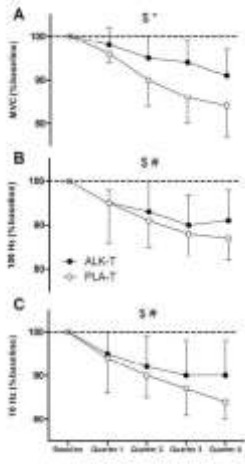
TABLES

Table 1: Assessment of neuromuscular fatigue and performance indicators at all stages of both conditions (ALK-T: Alkalosis trial; PLA-T: Placebo trial). # Significant group effect; \$ Significant time effect; * Significant interaction effect. All P<0.05. All data is presented in mean \pm SD

Variable		Condition	Baseline	Quarter 1	Quarter 2	Quarter 3	Quarter 4
MVC	\$,*	ALK-T	255 \pm 36	251 \pm 40	244 \pm 42	240 \pm 43	233 \pm 42
(N.m)		PLA-T	259 \pm 32	247 \pm 35	233 \pm 41	223 \pm 38	220 \pm 42
100 Hz	#,\$	ALK-T	72 \pm 7	69 \pm 7	67 \pm 9	65 \pm 8	65 \pm 6
(N.m)		PLA-T	70 \pm 8	67 \pm 10	64 \pm 8	62 \pm 9	61 \pm 9
10 Hz	#,\$	ALK-T	71 \pm 8	67 \pm 8	65 \pm 8	63 \pm 6	63 \pm 6
(N.m)		PLA-T	70 \pm 7	66 \pm 9	64 \pm 8	61 \pm 6	59 \pm 7
10:100 Hz		ALK-T	98 \pm 5	98 \pm 3	97 \pm 4	98 \pm 3	96 \pm 2
Ratio (%)		PLA-T	100 \pm 5	99 \pm 4	100 \pm 3	100 \pm 8	97 \pm 5
15m Sprint	\$	ALK-T		2.53 \pm 0.11	2.56 \pm 0.12	2.58 \pm 0.14	2.58 \pm 0.11
(s)		PLA-T		2.54 \pm 0.11	2.55 \pm 0.13	2.58 \pm 0.17	2.60 \pm 0.16
Layup (%)		ALK-T		92.7 \pm 7.2	82.7 \pm 12.5	86.4 \pm 13.0	87.3 \pm 9.8
		PLA-T		88.2 \pm 4.4	89.1 \pm 5.7	85.4 \pm 7.7	86.4 \pm 10.7



ACCEPTED



ACCEPTED