

1 **Pre-exercise carbohydrate feeding and high-intensity exercise capacity: effects of timing**  
2 **of intake and carbohydrate concentration.**

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27 **ABSTRACT**

28 The present study aimed to investigate the influence of timing of pre-exercise carbohydrate  
29 feeding (Part A), and carbohydrate concentration (Part B), on short-duration high-intensity  
30 exercise capacity. In Part A, seventeen males, and in Part B ten males, performed a peak  
31 power output (PPO) test, two familiarisation trials at 90% of PPO, and 4 (for Part A) or 3 (for  
32 Part B) experimental trials involving exercise capacity tests at 90% PPO. In Part A, the 4 trials  
33 were conducted following ingestion of a 6.4% carbohydrate/electrolyte sports drink ingested 30  
34 (C30) or 120 (C120) minutes before exercise, or a flavour-matched placebo administered either  
35 30 (P30) or 120 (P120) minutes before exercise. In Part B, the 3 trials were performed 30  
36 minutes after ingestion of 0%, 2% or 12% carbohydrate solutions. All trials were performed in a  
37 double blind cross-over design following and overnight fast. Dietary intake and activity in the two  
38 days before trials was recorded and replicated on each visit. Glucose, lactate, heart rate and  
39 mood/arousal were recorded at intervals during the trials. In Part A, C30 produced the greatest  
40 exercise capacity (mean±SD; 9.0±1.9 min, P<0.01) compared with all other trials (7.7±1.5 min  
41 P30, 8.0±1.7 min P120, 7.9±1.9 min C120). In Part B, exercise capacity (min) following  
42 ingestion of the 2% solution (9.2±2.1) compared with 0% (8.2±0.7) and 12% (8.0±1.3) solutions  
43 approached significance (p=0.09). This study provides new evidence to suggest that timing of  
44 carbohydrate intake is important in short duration high-intensity exercise tasks, but a  
45 concentration effect requires further exploration.

46

47

## 48 INTRODUCTION

49 The majority of studies examining the effects of carbohydrate feeding on exercise performance  
50 and exercise capacity have focused on carbohydrate ingestion during prolonged exercise, or on  
51 pre-exercise carbohydrate feeding in the few hours or minutes before prolonged endurance  
52 activities (for reviews see Cermak & Van Loon, 2013; Temesi et al., 2011; Karelis et al., 2010;  
53 Jeukendrup & Killer, 2010). There has been limited focus on carbohydrate feeding prior to short  
54 duration (<10 min), high-intensity (>85% max), exercise tasks, presumably because it is  
55 acknowledged that muscle glycogen depletion will not be limiting during exercise of this nature.  
56 As a result, guidelines for pre-event fuelling focus on providing information about carbohydrate  
57 intake before endurance exercise tasks lasting longer than 60 minutes (Burke et al., 2011).  
58 Current guidelines specify that there is no requirement for ingestion of carbohydrate before  
59 events lasting less than 45 minutes. Furthermore, it is recognized that ingestion of carbohydrate  
60 in the immediate pre-exercise period (30-60 minutes before exercise) can reduce liver glucose  
61 output, stimulate glucose uptake and oxidation and induce a rebound hypoglycaemia in  
62 susceptible individuals (Williams and Lamb, 2008; Jeukendrup & Killer, 2010). Interestingly,  
63 these known metabolic effects of pre-exercise feeding have not been considered for their  
64 potentially beneficial impact on high-intensity short-duration exercise.

65

66 Pre-exercise elevation of blood glucose and insulin increases glucose uptake and oxidation in  
67 contracting skeletal muscle (Febbraio et al., 2000a,b; Tsintzas et al., 2000) through activation of  
68 the pyruvate dehydrogenase enzyme complex (PDC). It has also been shown that  
69 pharmacological activation of PDC reduces phosphocreatine degradation and muscle lactate  
70 accumulation during short intense muscle contraction protocols (Timmons et al., 1998). It could  
71 therefore be hypothesized that the correct timing and concentration of pre-exercise  
72 carbohydrate feeding, to maximize glucose uptake and oxidation, could aid in matching supply  
73 and demand for ATP by contracting skeletal muscle during short duration high-intensity exercise

74 tasks. A novel interpretation of this metabolic impact of pre-exercise carbohydrate feeding would  
75 be to suggest that an increased glucose uptake and oxidation early in exercise could help to  
76 delay the development of fatigue in high-intensity short-duration tasks. This would be  
77 particularly true for tasks lasting less than 10 minutes during which time the stimulus to  
78 carbohydrate oxidation would be at its greatest. To date, no studies have investigated this  
79 possible action of carbohydrate feeding prior to high-intensity exercise. Therefore, more  
80 research is needed to define the effects of carbohydrate feeding prior to short-duration high-  
81 intensity exercise before we fully dismiss any need for carbohydrate intake prior to high-intensity  
82 exercise tasks.

83

84 We therefore hypothesized that feeding carbohydrate 30 minutes before exercise would result in  
85 improved high-intensity exercise capacity compared with feeding 120 min before exercise, and  
86 we hypothesized that the size of this effect may reflect the pre-exercise elevation in plasma  
87 glucose concentration in a dose-response manner.

88

## 89 **METHODOLOGY**

90 The study was performed as two separate parts. Part A addressing the primary aim of  
91 examining timing of carbohydrate intake on high-intensity exercise capacity, and Part B  
92 addressing the secondary aim of the impact of carbohydrate concentration on high-intensity  
93 exercise capacity.

94

### 95 **Participants**

96 Participants in Part A were 17 male volunteers and in Part B were 10 male volunteers. All  
97 volunteers were recreationally active team sport players (Table 1). Prior to taking part in the  
98 study participants were fully informed, both through written and verbal information, as to the  
99 purposes of the study and of the risks involved. Pre-participation screening in the form of

100 general health questionnaires and physical activity questionnaires were administered prior to  
101 participation. Each participant then gave their written informed consent. The experimental  
102 protocols for Part A and Part B were both approved by the University of Stirling Ethics  
103 Committee. All volunteers involved in Part A and Part B of the study completed 3 preliminary  
104 visits prior to the main experimental trials. All sessions were conducted one week apart and at  
105 the same time of day, in the morning after an overnight fast (10-12 hours).

106

107 The preliminary visits required the participants to report to the laboratory for pre-screening  
108 followed by a maximal incremental exercise test, and for two high-intensity exercise capacity  
109 habituation trials. The maximal exercise test was conducted on an electrically braked cycle  
110 ergometer (Sensormedics Ergoline 900) to determine peak power output (PPO) using a  
111 modified method of Hawley and Noakes (1992). Briefly, the starting work load was calculated in  
112 respect to each subject's body mass (2.5W/kg) and increased by 50W after 150 seconds and  
113 thereafter increased by 25W every 150 seconds until volitional exhaustion (failure to sustain a  
114 cadence above 60 rpm). PPO was then calculated according to the formula:  $PPO = W_{final} +$   
115  $([t/150] * 25)$  where  $W_{final}$  is the final workload attained and t is the elapsed time achieved during  
116 the stage. 25 is a constant reflecting the load increase per stage. During the initial PPO  
117 assessment verbal encouragement was provided by the researchers.

118

119 Having calculated each participant's PPO, two practice trials were then undertaken on the cycle  
120 ergometer at 90% of their PPO and work was sustained until volitional exhaustion (cadence  
121 could not be sustained above 60 rpm). During these high-intensity exercise capacity tests  
122 encouragement was withheld and no music provided to ensure that participants were not  
123 influenced by the researchers/environment. Participants also completed a mood/arousal  
124 questionnaire (Brunel Mood Scale (BRUMS); Terry et al., 1999) and blood sampling procedures  
125 were performed. On completion of these preliminary visits the participants entered into the

126 experimental phase of the studies and either undertook four experimental trials for Part A or  
127 three experimental trials for Part B administered using a Latin square randomization procedure.  
128 Since Part A of the study was completed first we conducted an *a priori* sample size estimate  
129 based upon the Part A data but also based upon recruitment of a more homogenous group (of  
130 similar age, training status and peak power output) competing in University team sports. Our  
131 sample size estimate was based on 95% confidence limits, 80% power, pooled SD of 1 min and  
132 a mean difference detectable between trials of 1 min. This provided an estimate of n=8 for Part  
133 B and hence n=10 were recruited.

134

### 135 ***Experimental Procedures - Part A.***

136 In Part A of the study, four experimental trials were undertaken in a double blind cross-over  
137 randomization design with 7 days between trials. Participants were asked to keep a food and  
138 activity diary for 48 hours prior to the first experimental trial and to not undertake any moderate  
139 or intense activity during the 24 hours before the trial. Participants then replicated their dietary  
140 intake and activity in the 48 hours prior to each of the subsequent experimental trials which was  
141 confirmed verbally on the morning of each trial using a checklist. All trials were carried out in the  
142 morning after an overnight fast (>10 hours). Each participant reported to the laboratory in the  
143 morning (between 8-10 a.m.) and body mass was recorded prior to completing an initial  
144 evaluation of mood/arousal using the BRUMS questionnaire. BRUMS has been used to  
145 successfully assess mood/arousal changes from pre- to post- exercise in previous studies  
146 (Milton et al., 2005; Terry et al., 2012). Following completion of the BRUMS a capillary blood  
147 sample was obtained for determination of baseline plasma glucose and plasma lactate  
148 concentration. Participants then ingested a single 500ml bolus of either a commercially available  
149 carbohydrate-electrolyte beverage (6.4% carbohydrate, 32g, C) or a flavour and colour matched  
150 placebo (0.1% carbohydrate, P). The composition of the drinks is shown in Table 2. On two of  
151 the trials there was a 30 minute seated rest period (C30 and P30) and on the other two a 2 hour

152 seated rest period (C120 and P120) between ingestion of the drink bolus and the start of the  
153 high-intensity exercise capacity test. Following the rest period (immediately before exercise) a  
154 further BRUMS questionnaire was completed and another capillary blood sample was obtained.  
155 A heart rate monitor was fitted and subjects were given a 5 minute warm up at half of their 90%  
156 PPO workload. After completion of the warm up participants cycled at 90% of PPO until  
157 volitional exhaustion. Heart rate was recorded throughout exercise and no verbal  
158 encouragement or music was provided on any of the trials. A final BRUMS questionnaire was  
159 completed immediately after the end of exercise and a final capillary blood sample was obtained  
160 3 minutes following completion of exercise. A schematic of the protocol is shown in Figure 1.

161

#### 162 ***Experimental Procedures - Part B.***

163 In Part B of the study, three experimental trials were carried out in a single blind cross-over  
164 design with trials conducted one week apart. Participants also completed both a food and  
165 exercise diary to enable standardisation to occur within each participant as described for Part A.  
166 All trials were carried out in the morning after an overnight fast (>10 hrs). On arrival at the  
167 laboratory body mass was recorded prior to completing an initial evaluation of mood/arousal  
168 using the BRUMS questionnaire.

169

170 Following these initial measurements a small capillary blood sample was obtained for  
171 determination of baseline plasma glucose and lactate concentration. Participants then ingested  
172 either a flavour and colour matched placebo (0%), a dilute carbohydrate beverage (2%) or a  
173 concentrated carbohydrate beverage (12%) as a bolus equating to  $7.5 \text{ ml} \cdot \text{kg}^{-1}$ . The composition  
174 of the drinks is shown in Table 2. On average this equated to ingestion of 11.5g of carbohydrate  
175 for the 2% trial and 68.8g of carbohydrate for the 12% trial. The fluid consumed was delivered in  
176 a single blind randomized cross-over fashion and was ingested 30 minutes prior to the start of  
177 the high-intensity exercise capacity test. During the 30 minute rest period participants remained

178 in the laboratory and were fitted with a heart rate monitor (Polar Electro, Finland). Following the  
179 rest period, another blood sample was obtained and a further BRUMS questionnaire completed  
180 immediately prior to taking position on the cycle ergometer. Participants were given a 5 minute  
181 warm up at half of their 90% PPO workload and, after completion of the warm up, then cycled at  
182 90% of PPO until volitional exhaustion. Heart rate was recorded throughout exercise and rating  
183 of perceived exertion (RPE, Borg, 1982) was recorded at 2 min, 5 min and at the end of  
184 exercise. Blood samples were obtained at 2 min and 5 min during exercise, then 3 min after  
185 reaching volitional exhaustion. No verbal encouragement or music was provided on any of the  
186 trials. A final BRUMS questionnaire was completed immediately following exercise. A schematic  
187 of the study protocol is shown in Figure 1. In all trials blood sample analyses for glucose and  
188 lactate were performed immediately upon collection using an Electrolyte Metabolite Laboratory  
189 analyser (EML105, Radiometer, Copenhagen).

190

### 191 ***Statistical analysis***

192 In Part A and Part B baseline blood sample values from each experimental trial were compared  
193 using one-way ANOVA. Exercise capacity was analysed using Student's paired T-tests with  
194 Bonferroni correction. Metabolites, heart rate and mood/arousal scores were assessed using  
195 repeated measures ANOVA to determine trial, time, or trial x time interaction effects. Change in  
196 mood/arousal subscale scores between baseline and pre-exercise were assessed using one-  
197 way ANOVA. Pearson correlation analysis was used to examine associations between plasma  
198 glucose elevation and exercise capacity. All data are expressed as Mean (SD) or Mean (95%  
199 confidence interval) in the text and Tables, and as Mean (SEM) in Figures. Significance was  
200 accepted at  $p < 0.05$  or the Bonferroni adjusted value of  $p < 0.008$  for exercise capacity in Part A,  
201 and  $p < 0.016$  for exercise capacity in Part B.

202

203



## 204 RESULTS

205 All participants completed the trials and none had any side effects such as gastrointestinal  
206 distress from any of the drinks ingested.

207

### 208 Part A – Timing of intake

209 High-intensity exercise capacity was significantly influenced by timing of CHO ingestion.  
210 Ingestion of a 6.4% carbohydrate drink 30 minutes before exercise resulted in a significantly  
211 greater exercise capacity than all other trials ( $P < 0.008$ , Figure 2A). The greatest mean (95% CI)  
212 difference in exercise capacity was between P30 and C30 trials with a 1.27 (0.72, 1.82) min  
213 improvement revealing the effect of carbohydrate feeding. However, there was a greater than 1  
214 minute improvement in exercise capacity when comparing C30 vs. C120 trials (1.06 (0.63, 1.50)  
215 min) revealing the effect of timing of carbohydrate intake. There was no difference in exercise  
216 capacity between P30 and P120 trials (0.28 (-0.25, 0.80) min) and no difference between P120  
217 and C120 trials (0.21 (-0.46, 0.87) min). This equates to a 17(4)% increase in exercise capacity  
218 on the C30 trial compared with the P30 trial, and a 14(3)% increase on C30 compared with the  
219 C120 trial.

220

221 Due to the timing differences in pre-exercise carbohydrate feeding in the study design there  
222 was, as expected, significant main effects of trial, time and an interaction (all  $P < 0.01$ ) for blood  
223 glucose. A higher pre-exercise plasma glucose concentration was observed on the C30 trial  
224 compared to all other trials (Figure 3) with no difference at baseline. Post-exercise plasma  
225 glucose was significantly lower on the C30 trial compared with P30 and P120 only. There was a  
226 significant but weak positive correlation between pre-exercise plasma glucose concentration  
227 and high intensity exercise capacity ( $r$  value of 0.26,  $P = 0.03$ ). No differences between trials and  
228 no interaction effects were observed with the plasma lactate data or heart rate response data  
229 (Figure 3).

230  
231 Mood subscale scores did not reveal any significant trial, time or trial x time interactions with the  
232 exception of a time effect on the Fatigue subscale score. Fatigue rating was significantly higher  
233 post-exercise than baseline or pre-exercise values on all trials. Change in mood score between  
234 baseline and immediately pre-exercise revealed a significant effect for the Tension subscale. A  
235 higher mean (SD) tension change score was observed on P120 (0.41(0.71) units) compared  
236 with C30 (-0.29 (0.59) units) and C120 (-0.18(0.73) units) trials. Increase in mean (SD) vigour  
237 scores (1.18(1.85) units) and reduction in fatigue scores (-1.35(1.73) units) from pre-drink to  
238 pre-exercise were greatest on the C30 trial but did not reach significance when compared with  
239 other trials.

240

#### 241 **Part B – Carbohydrate concentration**

242 High intensity exercise capacity was not significantly affected by the carbohydrate concentration  
243 ingested 30 minutes before exercise in Part B of the study ( $P=0.09$ ; Figure 2B). However, the  
244 mean (95% CI) difference in exercise capacity between 0% and 2% trials was 1.01 (-0.12, 2.14)  
245 min, and between 12% and 2% trials was 1.13 (-0.10, 2.37) min. The difference between 0%  
246 and 12% trials was 0.12 (-0.55, 0.80) min. Thus, the magnitude of difference in exercise  
247 capacity between the 2% trial and the other trials was similar to that observed between C30 and  
248 the other trials in Part A of the study. The effect equates to a mean (SD) increase of 12(21)% in  
249 exercise capacity on the 2% trial compared with the 0% trial, and a 15(25)% increase from the  
250 12% trial. Post-trial sample size calculations revealed that for 80% power with a pooled SD of  
251 1.33 and a mean difference of 1.07 min a sample size of 13 would be required to detect a  
252 significant effect.

253

254 Due to the differing carbohydrate concentration of ingested drinks there were significant main  
255 effects of trial, time and trial x time for plasma glucose response (Figure 4). There was no

256 difference in baseline plasma glucose concentration but a higher pre-exercise plasma glucose  
257 concentration was observed on the 12% trial compared with 2% and 0% ( $P<0.01$ ), and on the  
258 2% trial compared with the 0% trial ( $P<0.01$ ). These differences remained following 2 minutes of  
259 the high intensity exercise task but were not apparent when 5 minutes of exercise had been  
260 completed. No differences were noted between trials for post-exercise glucose concentration.  
261 No differences between trials and no interactions were observed for plasma lactate or heart rate  
262 responses to exercise (Figure 4). No differences in RPE were noted between trials but there  
263 was a significant time effect with RPE increasing from 15(2) at 2 min, to 18(1) at 5 min and to  
264 20(0) at the point of exhaustion on all trials.

265  
266 Mood subscale scores did not reveal any significant trial, time, or trial x time interactions.  
267 Change in mood score between baseline and immediately pre-exercise also did not reveal any  
268 significant differences between trials (data not shown).

269

## 270 **DISCUSSION**

271 The two parts of the present study have provided interesting new insights into a possible benefit  
272 of pre-exercise carbohydrate ingestion on high-intensity short duration exercise capacity. In Part  
273 A, the key observation was that high-intensity exercise capacity was significantly improved by  
274 ingestion of 32g of carbohydrate taken 30 minutes before exercise (14-17% increase),  
275 compared with ingestion of 32g of carbohydrate 2 hrs before exercise, or placebo solutions  
276 ingested 30 minutes or 2 hours before exercise. In Part B, a similar magnitude of change (12-  
277 15% increase) in exercise capacity, albeit not reaching statistical significance, was observed  
278 over 0% and 12% pre-exercise carbohydrate ingestion trials when a 2% carbohydrate solution  
279 was ingested 30 minutes before exercise. These combined observations from Part A and Part B  
280 suggest there is an optimal timing of ingested carbohydrate for short duration high-intensity  
281 exercise tasks lasting <10 minutes, but more work is required to determine whether there is an

282 optimal concentration. These observations also require more detailed mechanistic exploration in  
283 future studies.

284

### 285 **Part A - Timing of carbohydrate intake**

286 Research on the metabolic effects of pre-exercise carbohydrate feeding has usually been  
287 confined to examination of effects on prolonged endurance exercise tasks. Many studies have  
288 adopted a fixed workload exercise period followed by a performance task (Moseley et al., 2003;  
289 Jentjens et al., 2003), or have examined prolonged continuous or intermittent endurance tasks  
290 (Pritchett et al., 2008). The fixed workload period in these studies has revealed that metabolic  
291 disturbances from carbohydrate feeding are short-lived and typically only remain evident during  
292 the first 10-15 minutes of prolonged activity when carbohydrate is ingested 15-30 minutes prior  
293 to exercise, and are often not evident at all if carbohydrate is ingested 75-120 minutes before  
294 exercise. Other studies also reveal that there is an accelerated glucose uptake/oxidation by  
295 contracting skeletal muscle in the early stages of exercise when pre-exercise blood glucose  
296 concentration is elevated (Febbraio et al., 2000a,b; Tsintzas et al., 2000). To date, there have  
297 been no investigations specifically exploring the potential for these metabolic disturbances,  
298 induced by pre-exercise carbohydrate feeding, to benefit high-intensity exercise capacity. In  
299 particular, during exercise tasks that last only as long as the metabolic disturbance itself, it may  
300 be possible to maximize glucose uptake / oxidation in the early stages of exercise, and  
301 positively influence high-intensity exercise capacity

302

303 The greater exercise capacity noted in the present study when carbohydrate was ingested 30  
304 minutes before exercise would initially appear to support the hypothesis that elevated pre-  
305 exercise glucose benefits high-intensity exercise tasks. Indeed, it is likely that plasma insulin  
306 would also be elevated immediately pre-exercise on the C30 trial. The combined effect of high  
307 insulin and high glucose before exercise would act to blunt the mobilization and oxidation of

308 fatty acids (Bonen et al., 1981) and would push metabolism towards increased carbohydrate  
309 oxidation by blunting hormone sensitive lipase activity and activating the pyruvate  
310 dehydrogenase enzyme complex (Watt et al., 2004; Tsintzas et al., 2000). In high intensity  
311 efforts lasting only 8-10 minutes there is still a significant aerobic component, and an increased  
312 flux through glycolysis in the early stages of exercise would aid metabolic integration/regulation  
313 i.e. better matching of ATP supply with demand for ATP (Timmons et al., 1998). Indeed,  
314 Timmons et al. (1998) demonstrated that activation of the pyruvate dehydrogenase enzyme  
315 complex (PDC) with dichloroacetate improves fatigue resistance in a single leg ischaemic  
316 exercise model. These previous studies provide a clear metabolic explanation for the current  
317 findings of improved exercise capacity in the present study, and the lower post-exercise glucose  
318 concentration noted in the C30 trial of the present study may provide some indirect evidence to  
319 support greater glucose uptake and oxidation, but this may not be the whole answer.

320  
321 The improvement in exercise capacity observed in the present work was not convincingly  
322 associated with the pre-exercise plasma glucose concentration, or a change in concentration  
323 from pre-drink to pre-exercise. It is also worth considering that the effect of enhanced glucose  
324 uptake and oxidation in non-ischaemic contracting muscle is likely to be small, and it could be  
325 argued that the lower plasma glucose concentration following exercise just reflects the longer  
326 total exercise duration on that trial. Therefore, other explanations for the enhanced exercise  
327 capacity should be considered. In the present study the participants were overnight fasted.  
328 Although liver glycogen stores would not be fully depleted on entry to the laboratory (Casey et  
329 al., 2000) feeding of carbohydrate on the C30 and C120 trials might be expected to contribute to  
330 liver glycogen stores. It is also probable that the elevation in liver glycogen content would be  
331 greater on the C120 trial due to the expected time course of storage (Casey et al., 2000). This  
332 would suggest that differences in liver glycogen content are not playing a key role in influencing  
333 high-intensity exercise capacity in the present study, although further investigation is necessary

334 before this can be ruled out. Another factor worth considering is the impact of the seated rest  
335 period on the exercise capacity outcome. It may have been prudent to have participants seated  
336 for 90 minutes before the ingestion of carbohydrate or placebo in the C30 and P30 trials.  
337 However, the lack of any difference in exercise capacity between P30 and P120 trials would  
338 suggest that any impact of seated rest duration is likely to be small.

339  
340 These preliminary observations suggest that metabolic factors probably have a part to play in  
341 the enhanced exercise capacity on the C30 trial, but other non-metabolic explanations should  
342 also be considered. It is possible that a positive temporal mood/arousal alteration to feeding of  
343 carbohydrate (increased vigour, decreased fatigue) would occur when carbohydrate was  
344 ingested 30 minutes before exercise, and that a potentially negative mood/arousal alteration  
345 (increased fatigue) would occur when carbohydrate was ingested 2 hr before exercise (Benton  
346 and Owens, 1993, Berridge and Robinson, 1998; Benton, 2002). However, the data obtained in  
347 the present study do not support this hypothesis, but may be limited by the sensitivity of the  
348 methodological approach. It is also possible that the positive exercise capacity outcome  
349 observed on the C30 trial is linked to other central neural effects of carbohydrate feeding,  
350 possibly including oral sensing of carbohydrate ingestion and altered neuromuscular control  
351 (Rollo et al., 2010; Chambers et al., 2009; Carter et al., 2004; Lambert et al., 2005; Gant et al.,  
352 2010). However, there are considerable differences between the mouth rinse literature and our  
353 current experimental approach, not least of which is the exercise intensity and duration. The  
354 mouth rinsing studies typically examine performance tasks lasting around 1 hour, and the  
355 magnitude of positive effect is in the region of 1-4%. This contrasts to our use of a short duration  
356 high intensity exercise capacity test, but we have observed moderate positive improvements of  
357 around 15% which could also be expected to translate to a performance improvement in the  
358 region of 1-4%. Since mouth rinsing is usually conducted during the warm-up phase in the  
359 previous protocols and mainly uses drinks containing around 6% carbohydrates, it would seem

360 prudent to apply these methods to investigate mechanisms for enhanced exercise  
361 capacity/performance with carbohydrate feeding in future high-intensity exercise studies.

362

### 363 **Part B – Carbohydrate concentration**

364 Given that timing of carbohydrate intake appears important and that it likely reflects both  
365 metabolic and neural effects of carbohydrate ingestion, there may also be an optimal dose  
366 effect of carbohydrate for high-intensity short-duration exercise capacity tasks. In Part B of the  
367 study, although we did not observe a statistically significant effect of carbohydrate concentration  
368 on exercise capacity, we have provided some evidence for a concentration mediated effect.  
369 Exercise capacity was similar on all (0%, 2% and 12%) trials. The non-significant increase in  
370 exercise capacity on the 2% trial suggests further work should be done with larger sample sizes.

371

372 Previous work has shown a dose-response relationship between glucose feeding and central  
373 cognitive function tasks in older adults (Parsons and Gold, 1992). Enhanced memory following  
374 glucose ingestion, compared with placebo, occurred when 25g of glucose was ingested but not  
375 when 10g or 50g of glucose was ingested. This inverse U type effect of glucose on cognitive  
376 function tasks has also been demonstrated in animal models and in other human studies (Gold,  
377 1995). If these concepts were to hold true for effects on centrally driven improvements in  
378 exercise capacity then there could be an optimal carbohydrate concentration for maximizing  
379 high-intensity exercise capacity or performance. Given the observations of Parsons and Gold  
380 (1992) and others, it is likely that we may have missed the optimal concentration of  
381 carbohydrate in the present study since our participants ingested on average 0g, 11.5g and  
382 68.8g of carbohydrate prior to each exercise trial. It may be that ingestion of a 4-6% solution  
383 which would have provided around 24-34g of carbohydrate might have been closer to an  
384 optimal dose for metabolic and central neural effects. The 6.4% solution providing 32g of  
385 carbohydrate in Part A of our study demonstrated a significant impact upon exercise capacity,

386 and therefore may indirectly provide some evidence to support a dose-response. However, this  
387 observation needs to be assessed within a single study protocol to confirm this assertion.

388  
389 Interestingly, McConnell et al. (1996) examined the effects of carbohydrate feeding and blood  
390 glucose elevation in the last 30 minutes of a 2 hour cycle ride on a subsequent 15 minute high-  
391 intensity exercise performance task. In their study, participants ingested either placebo (0%  
392 CHO) or a 7% CHO solution throughout the 2 hour ride, or ingested placebo for 90 min followed  
393 by a 21% CHO solution in the final 30 minutes. Not surprisingly, blood glucose concentration at  
394 the end of the 2 hour ride was highest in the trial where the 21% solution was ingested, was  
395 intermediate with the 7% and lowest with the 0% solutions. No difference in total amount of work  
396 performed in 15 minutes was observed between 0% (242(9) KJ) and 21% (253(10) KJ) trials,  
397 but total work performed was greater in the 7% trial (268(8) KJ). These data appear to add to  
398 the notion that there may be an optimal drink concentration prior to high-intensity exercise tasks.

399  
400 Our observations of a clear timing of intake effect, and the suggestion of a dose-response  
401 effect, provide a sound basis from which to more fully investigate pre-exercise carbohydrate  
402 feeding strategies for high-intensity exercise capacity. The potential translation to exercise  
403 performance and practical guidance for athletes requires further study focusing on central  
404 neural, metabolic, or peripheral neuromuscular control mechanisms.

405

406

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483

#### 484 **DECLARATION OF FUNDING SOURCES AND CONFLICT OF INTEREST**

485 This project was supported by University of Stirling, School of Sport. SDRG has received  
486 support for research from sport drink manufacturers in the past but none were involved in  
487 funding or supporting the present work.

488

489 **FIGURE LEGENDS.**

490 **Figure 1:** Study design schematic diagrams detailing the experimental trial protocols for Part A  
491 (timing of intake) and Part B (concentration of carbohydrate) sections of the study.

492 **Figure 2.** Mean (SEM) high-intensity exercise capacity following ingestion of carbohydrate or  
493 placebo 30 minutes (C30, P30) or 2 hrs (C120, P120) before exercise in Part A (A), and  
494 following ingestion of 0%, 2% and 12% carbohydrate solutions 30 minutes before exercise in  
495 Part B (B). a, b, d – indicate a significant difference from trials P30, P120, and C120,  
496 respectively.

497 **Figure 3:** Mean (SEM) plasma glucose concentration, plasma lactate concentration and heart  
498 rate during exercise following ingestion of carbohydrate or placebo 30 minutes (C30, P30) or 2  
499 hrs (C120, P120) before exercise in Part A of the study. a, b, d – indicate a significant difference  
500 from trials P30, P120, and C120, respectively.

501 **Figure 4:** Mean (SEM) plasma glucose concentration, plasma lactate concentration and heart  
502 rate during exercise following ingestion of carbohydrate or placebo 30 minutes (C30, P30) or 2  
503 hrs (C120, P120) before exercise in Part B of the study. a, b, c – indicate a significant difference  
504 from trials 0%, 2% and 12%, respectively.

505

506 **Table 1:** Mean (SD) participant characteristics obtained on the initial laboratory visit for Part A  
 507 (timing of carbohydrate intake study) and Part B (concentration of carbohydrate intake study).

	<b>Part A</b>	<b>Part B</b>
n	17	10
Age (yr)	23.6 (4.8)	21.2 (0.8)
Height (m)	181.6 (6.4)	179.1 (4.9)
Mass (kg)	75.5 (6.9)	76.4 (5.0)
Peak power output (W)	270 (32)	312 (23)

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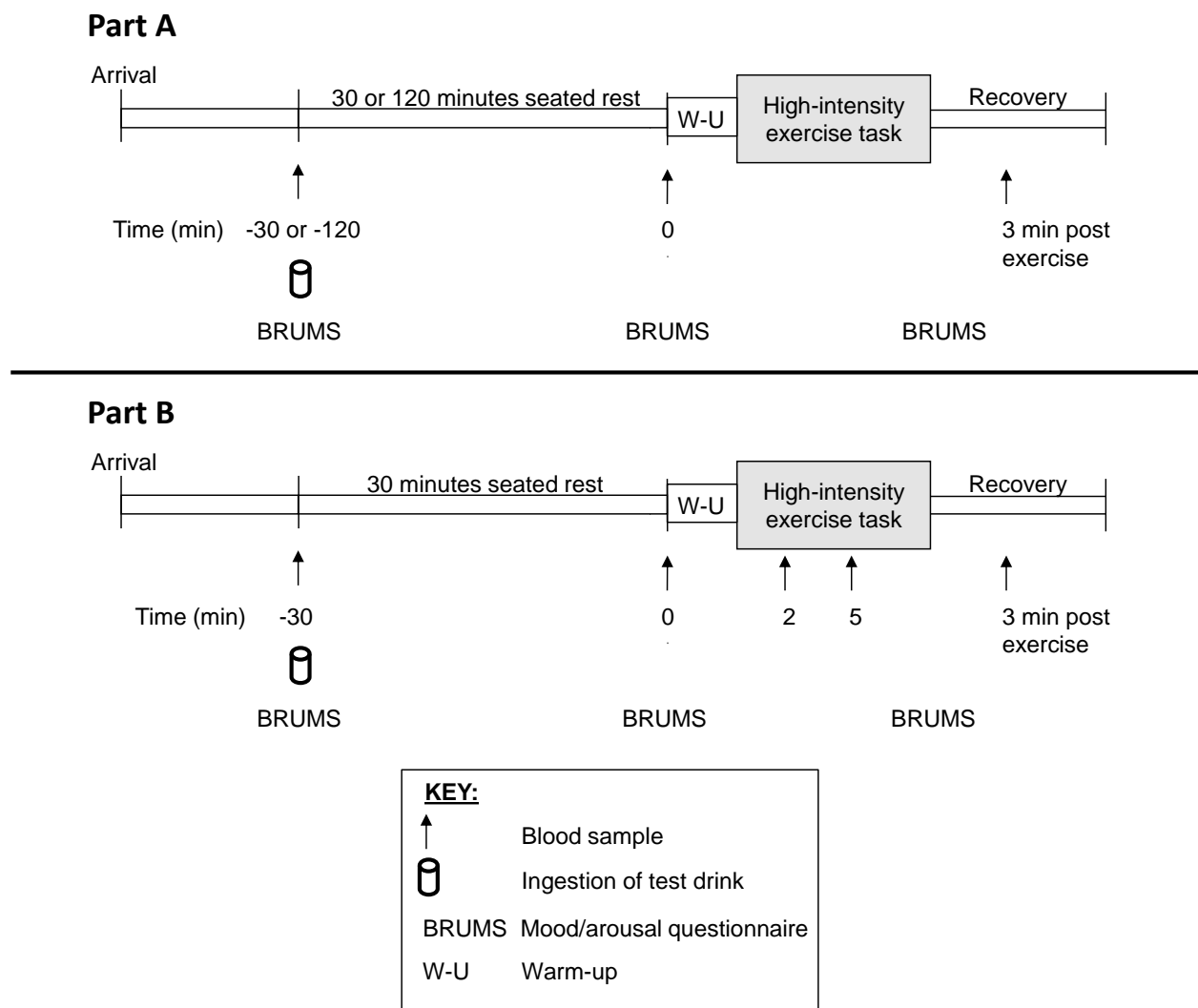
509 **Table 2:** Composition of the drinks ingested in Part A (timing of carbohydrate intake study) and  
 510 Part B (concentration of carbohydrate intake study).

	<b>Part A</b>	<b>Part B</b>
0% drink	Colour and flavour matched water	Colour and flavour matched water
2% drink	-	20 g/L glucose solution with low calorie flavouring
6.4% drink	64 g/L commercially available carbohydrate/electrolyte drink (24mM Na <sup>+</sup> )	-
12% drink	-	120 g/L glucose/maltodextrin solution with low calorie flavouring

511

512 **Figure 1.**

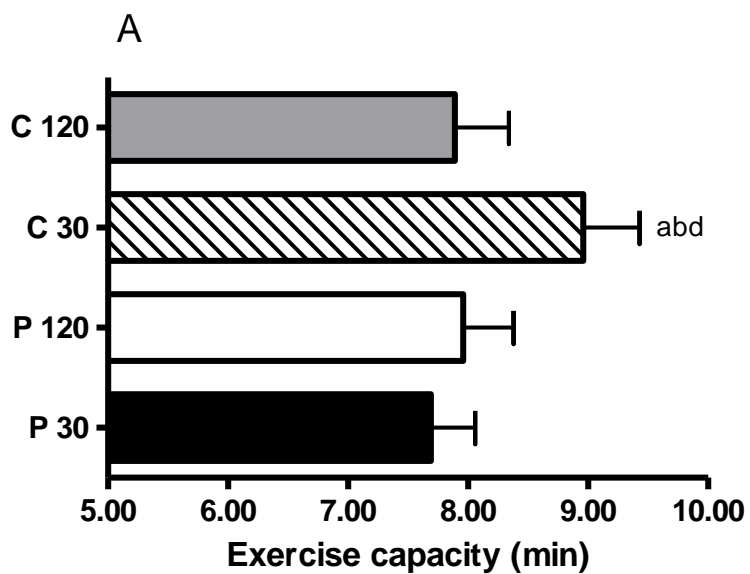
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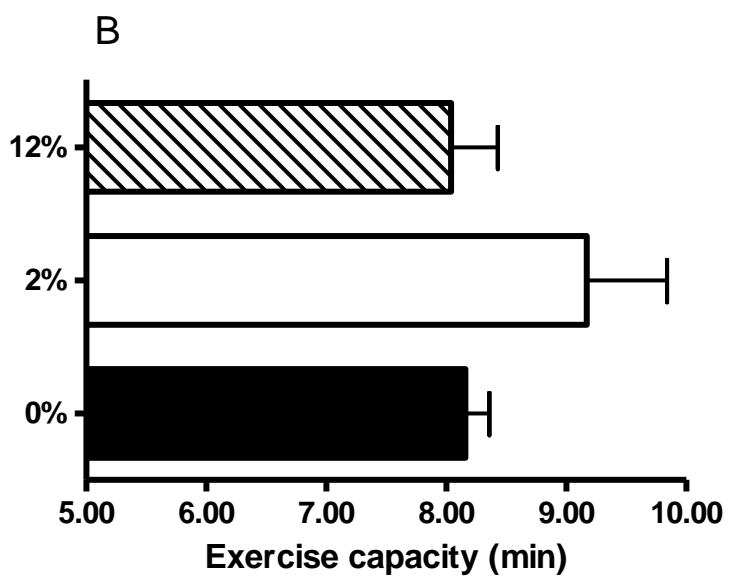
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516 Figure 2.



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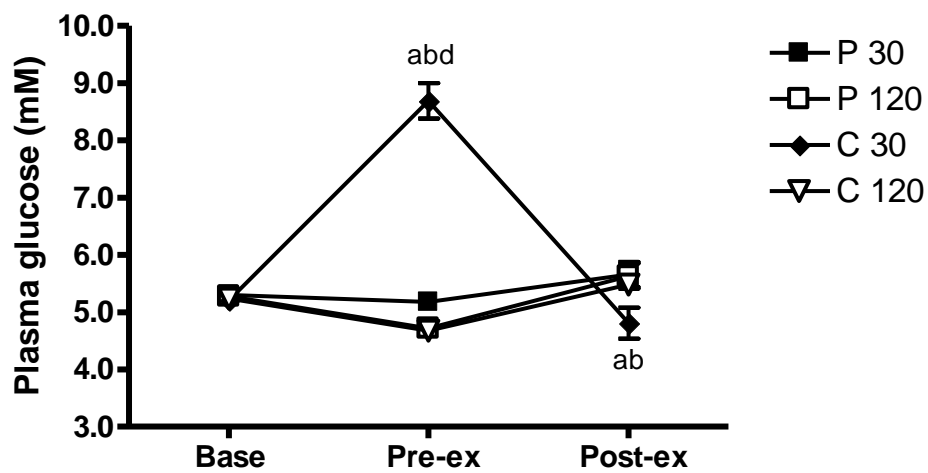


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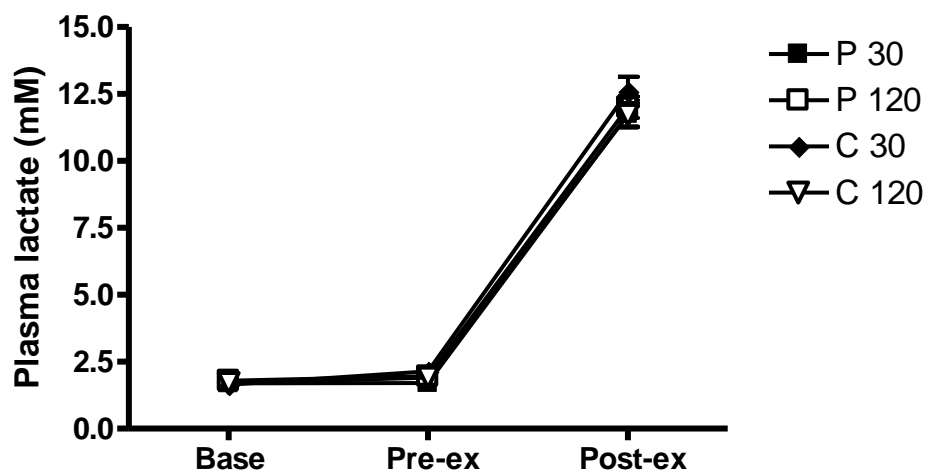
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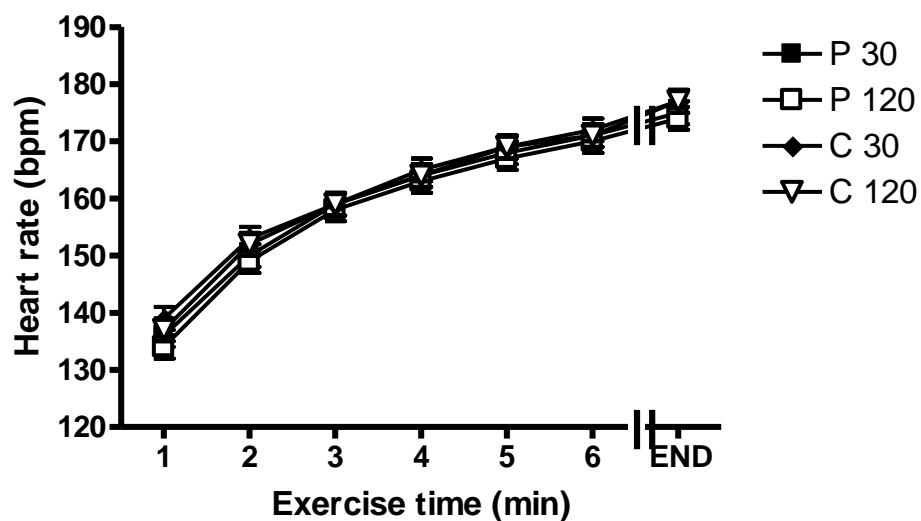
520 Figure 3.



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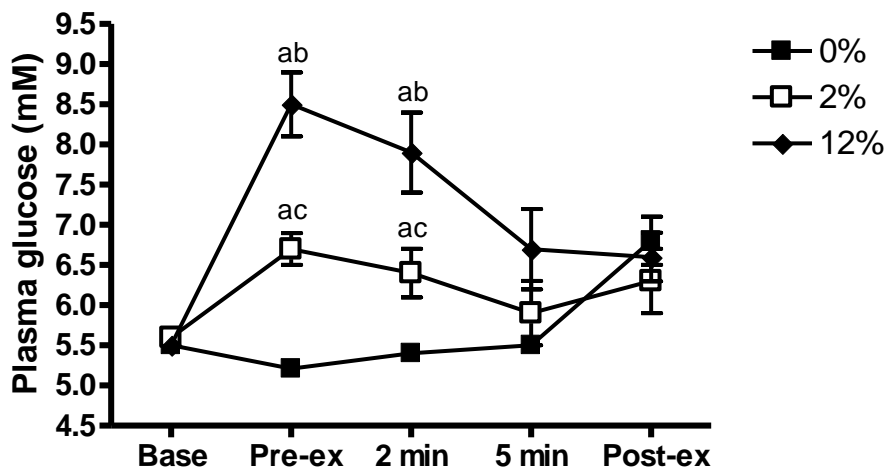


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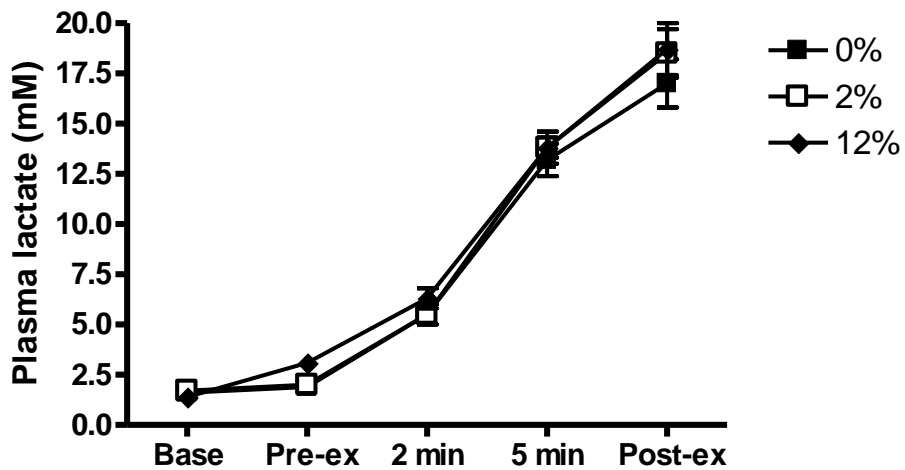


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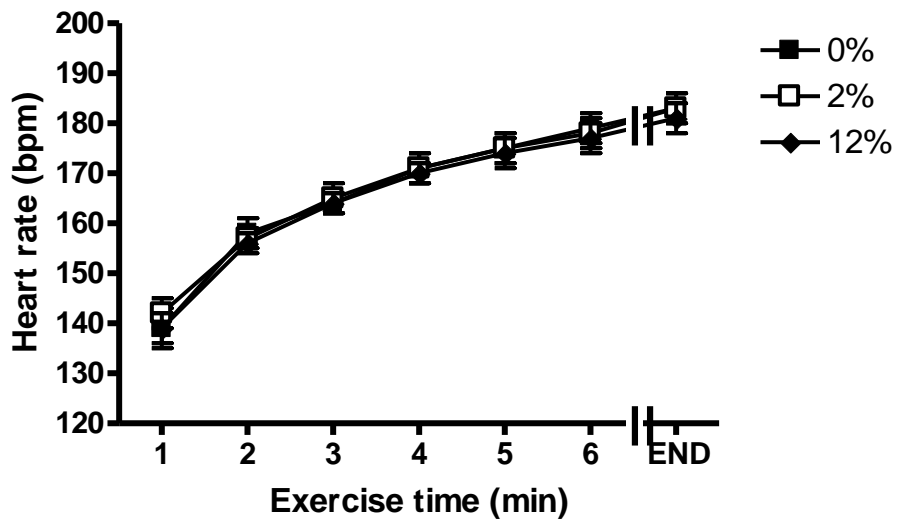
524 Figure 4.



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