



Citation for published version:

McGawley, K, Shannon, O & Betts, J 2012, 'Ingesting a high-dose carbohydrate solution during the cycle section of a simulated olympicdistance triathlon improves subsequent run performance', *Applied Physiology Nutrition and Metabolism*, vol. 37, no. 4, pp. 664-671. <https://doi.org/10.1139/H2012-040>

DOI:

[10.1139/H2012-040](https://doi.org/10.1139/H2012-040)

Publication date:

2012

Document Version

Peer reviewed version

[Link to publication](#)

University of Bath

Alternative formats

If you require this document in an alternative format, please contact:
openaccess@bath.ac.uk

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

1 **Ingesting a high-dose carbohydrate solution during the cycle section of a**
2 **simulated Olympic-distance triathlon improves subsequent run**
3 **performance**

4

5 Kerry McGawley^{1,2}, Oliver Shannon¹ and James Betts¹

6

7 ¹ Human Physiology Research Group, Department for Health, University of Bath, Claverton

8 Down, Bath, BA2 7AY, UK

9 ² Swedish Winter Sports Research Centre, Department of Health Sciences, Mid Sweden

10 University, 831 25 Östersund, Sweden

11

12 **Corresponding author:**

13 Dr. Kerry McGawley

14 Swedish Winter Sports Research Centre

15 Department of Health Sciences

16 Mid Sweden University

17 831 25 Östersund

18 Sweden

19

20 **Telephone:** +46 70 399 9874

21 **Fax:** +46 63 165 626

22 **E-mail:** kerry.mcgawley@miun.se

23

24 **Running Title:** Carbohydrate ingestion and triathlon

25

26 **ABSTRACT**

27

28 **Introduction:** The well-established ergogenic benefit of ingesting carbohydrates during
29 single-discipline endurance sports has only been tested once within Olympic-distance (OD)
30 triathlon. The aim of the present study was to compare the effect of ingesting a 2:1
31 maltodextrin:fructose (CHO) solution with a placebo (PLA) on simulated OD triathlon
32 performance. **Methods:** Six male and four female amateur triathletes (age, 25 ± 7 yr; body
33 mass, 66.8 ± 9.2 kg; $\dot{V}O_{2\text{peak}}$, 4.2 ± 0.6 L·min⁻¹) completed a 1500-m swim time-trial and an
34 incremental cycle test to determine $\dot{V}O_{2\text{peak}}$, before performing two simulated OD triathlons.
35 The swim and cycle sections of the main trials were of fixed intensities, while the run section
36 was completed as a time-trial. Two minutes prior to completing every quarter of the cycle
37 participants consumed 202 ± 20 mL of either a solution containing 1.2 g·min⁻¹ of
38 maltodextrin + 0.6 g·min⁻¹ of fructose at 14.4% concentration (CHO) or a sugar-free, fruit-
39 flavored drink (PLA). **Results:** The time-trial was $4.0 \pm 1.3\%$ faster during the CHO versus
40 PLA trial, with run times of 38 min 43 s \pm 1 min 10 s and 40 min 22 s \pm 1 min 18 s,
41 respectively ($P = 0.010$). Blood glucose concentrations were higher in the CHO versus PLA
42 trial ($P < 0.001$), while perceived stomach upset did not differ between trials ($P = 0.555$).
43 **Conclusion:** The current findings show that a 2:1 maltodextrin:fructose solution (1.8 g·min⁻¹
44 at 14.4%) ingested throughout the cycle section of a simulated OD triathlon enhances
45 subsequent 10-km run performance in triathletes.

46

47 **Key Words:** exercise, metabolism, fructose, glucose, maltodextrin, gastro-intestinal
48 discomfort, carbohydrate, sports nutrition, athlete performance

49

50 **INTRODUCTION**

51

52 Olympic-distance (OD) triathlon is a multi-disciplinary sport that involves a 1500-m swim, a
53 40-km cycle and a 10-km run performed in immediate succession. Research interest in
54 triathlon has developed over recent years, with a number of review articles emerging since
55 the turn of the millennium (Millet and Vleck 2000; Bentley et al. 2002; Jeukendrup et al.
56 2005; Bentley et al. 2008; Hausswirth and Brisswalter 2008; Peeling and Landers 2009). In
57 contrast to the relative wealth of data regarding the effect of swim and/or cycling strategies
58 on subsequent running and overall triathlon performance (Hausswirth et al. 2001;
59 Vercruyssen et al. 2002; Bernard et al. 2003; Peeling et al. 2005; Vercruyssen et al. 2005;
60 Suriano et al. 2007; Suriano and Bishop 2010), only one study has directly examined the
61 effect of carbohydrate ingestion on OD triathlon (Millard-Stafford et al. 1990).

62

63 In their study, Millard-Stafford et al. (1990) prescribed the co-ingestion of $\sim 0.5 \text{ g}\cdot\text{min}^{-1}$ of a
64 glucose polymer and $\sim 0.2 \text{ g}\cdot\text{min}^{-1}$ of fructose by means of a sports drink to a sample of
65 trained, male triathletes throughout the cycle and run sections of a simulated OD race.
66 Although there was a tendency for superior overall triathlon performance when consuming
67 the carbohydrate drink compared with the placebo, the improvement was not significant ($P <$
68 0.10). Considering the convincing body of evidence supporting the ergogenic benefits of
69 carbohydrate ingestion during single-discipline events (e.g. cycling or running) lasting $\geq 1 \text{ h}$
70 (Wright et al. 1991; Tsintzas et al. 1996; Carter et al. 2003; Temesi et al. 2011), the lack of a
71 statistically positive effect of carbohydrate ingestion on OD triathlon performance warrants
72 further investigation.

73

74 The absence of a significant performance benefit identified by Millard-Stafford et al. (1990)
75 following carbohydrate ingestion may be related to the relatively modest supplementation
76 quantities used. Indeed, conventional wisdom at the time dictated that exogenous
77 carbohydrate oxidation rates could not exceed $1 \text{ g}\cdot\text{min}^{-1}$, despite ingestion rates of $> 2 \text{ g}\cdot\text{min}^{-1}$
78 (Jeukendrup and Jentjens 2000). However, more recent studies have since revealed a capacity
79 for peak exogenous carbohydrate oxidation rates to reach $1.26 - 1.75 \text{ g}\cdot\text{min}^{-1}$ when ingesting
80 high doses (i.e., $1.8 - 2.4 \text{ g}\cdot\text{min}^{-1}$) of mixed carbohydrates, such as glucose + fructose
81 (Jentjens et al. 2004; Jentjens and Jeukendrup 2005). In addition, cycling endurance
82 performance has been significantly improved following the consumption of a 2:1
83 glucose:fructose solution ingested at a rate of $1.8 \text{ g}\cdot\text{min}^{-1}$ and 14.4% concentration (Currell
84 and Jeukendrup 2008). It is proposed that separate transporter proteins may enhance intestinal
85 carbohydrate absorption when multiple types of carbohydrate are ingested simultaneously
86 (Jentjens et al. 2004).

87

88 It remains to be established whether the recognized benefits of carbohydrate supplementation
89 during cycling and running necessarily translate to similar effects when the separate
90 disciplines are performed in sequence, as occurs during an OD triathlon. For example, the
91 mechanisms through which exogenous carbohydrate can offset fatigue may differ between
92 cycling and running, with an increased oxidation of blood glucose late in exercise observed
93 during cycling and a decreased rate of muscle glycogen depletion throughout exercise
94 observed during running (Tsintzas and Williams 1998). Based on these findings, there is
95 clearly a need to confirm whether carbohydrate supplements represent an effective nutritional
96 strategy for OD triathlon within the unique context of this multi-discipline event.

97

98 To this end, the aim of the current study was to investigate the ergogenic effects of ingesting
99 a 2:1 glucose polymer (i.e., maltodextrin) + fructose solution in volumes providing 1.8
100 $\text{g}\cdot\text{min}^{-1}$ during the cycle section of a simulated OD triathlon. Based on the existing literature,
101 it was hypothesized that ingesting $1.8 \text{ g}\cdot\text{min}^{-1}$ of a mixed carbohydrate solution would
102 improve 10-km run time relative to a matched quantity of a sugar-free, fruit-flavored placebo
103 drink.

104

105 **MATERIALS AND METHODS**

106

107 **Participants**

108

109 Ten amateur triathletes (mean \pm SD: age, 25 ± 7 yr; body mass, 66.8 ± 9.2 kg; $\dot{V}\text{O}_{2\text{peak}}$, $4.2 \pm$
110 $0.6 \text{ L}\cdot\text{min}^{-1}$), including four females (24 ± 5 yr; 59.8 ± 4.6 kg; $3.7 \pm 0.4 \text{ L}\cdot\text{min}^{-1}$) and six
111 males (26 ± 8 yr; 71.5 ± 8.6 kg; $4.5 \pm 0.5 \text{ L}\cdot\text{min}^{-1}$), volunteered to participate in the study. All
112 participants were training regularly (i.e., at least $5 \text{ days}\cdot\text{week}^{-1}$) and had previously competed
113 in at least two sprint or OD triathlon races. Time to complete an actual OD triathlon race ($n =$
114 8) was $2 \text{ h } 23 \text{ min } 43 \text{ s} \pm 10 \text{ min } 39 \text{ s}$ (1500-m swim: $25 \text{ min } 22 \text{ s} \pm 1 \text{ min } 38 \text{ s}$; 40-km cycle:
115 $1 \text{ h } 13 \text{ min } 22 \text{ s} \pm 6 \text{ min } 36 \text{ s}$; 10-km run: $43 \text{ min } 40 \text{ s} \pm 4 \text{ min } 03 \text{ s}$). Individuals were fully
116 informed of the procedures, requirements, benefits and risks associated with the study before
117 providing written informed consent. The study was approved by the ethics committee of the
118 Department for Health at the University of Bath, UK.

119

120 **Experimental overview**

121

122 Participants attended three testing sessions on separate days. The first session involved a
123 preliminary 1500-m swim time-trial (STT) and an incremental cycle test to volitional
124 exhaustion (RAMP). On both subsequent visits participants completed a simulated OD
125 triathlon (1500-m swim, 40-km cycle and 10-km run), where the work rates during the swim
126 and cycle sections were controlled and the run was treated as a time-trial (RTT). The two
127 simulated triathlon trials were separated by 5 – 12 days and were performed at the same time
128 in the morning to overcome any influence of circadian variance (Reilly and Brooks 1982).
129 All swimming was conducted in a 50-m indoor pool, which was heated to a constant
130 temperature of 27.5°C. Cycling was performed on a friction-braked cycle ergometer fitted
131 with standard toe-strap pedals (Monark Ergomedic 824E, Varberg, Sweden). The RTT
132 involved 5 x 2-km loops on a flat, asphalt surface within the University campus. Run distance
133 was measured using a cycle-mounted global positioning system (Garmin Edge 305, Garmin
134 International Inc., Olathe, KS).

135

136 **Preliminary tests**

137

138 The STT was used to determine individual swimming race pace. A standardized 500-m
139 warm-up (WU) involving 200 m of freestyle swimming, 200 m with a pull buoy and 100 m
140 of kicking was completed at a self-selected pace, followed by a 2-min recovery period, before
141 a 1500-m race-pace swim commenced. Participants were instructed to swim at the maximal
142 pace they could maintain within an OD triathlon (i.e., with a 40-km cycle and 10-km run to
143 follow). No time feedback was provided throughout the swim and a signal was given (by
144 submerging a kickboard beneath the water) prior to the final 100 m. The swim time was
145 recorded using a hand-held stopwatch and was subsequently used to control the swim pace
146 during the following two experimental trials.

147

148 The RAMP was completed 60 min after the STT in a laboratory where air temperature and
149 pressure were $20.3 \pm 1.7^{\circ}\text{C}$ and 745.6 ± 8.5 mmHg, respectively. Upon arrival, body mass
150 was measured to the nearest 0.1 kg and height was recorded to the nearest 0.1 cm using a
151 balance beam scale (Seca 700, Birmingham, UK). The handlebar and saddle positions on the
152 cycle ergometer were adjusted for individuals prior to testing and settings remained constant
153 during subsequent trials. Cycling commenced at an initial power output of 80 – 120 W (based
154 on estimated individual fitness) and was maintained at 85 $\text{revs}\cdot\text{min}^{-1}$. This cadence was
155 selected based on previous findings using triathletes (Vercruyssen et al. 2001) and was used
156 during all cycle components within the study.

157

158 The first stage of the RAMP was used as a warm-up and lasted 5 min. The flywheel
159 resistance was increased by 0.5 kg (~ 40 W) every 3 min thereafter until volitional
160 exhaustion. Expired air was collected for 60 s in Douglas bags after 1 min 45 s of each 3-min
161 stage and cycle cadence was recorded during these periods. A 6 – 20 Borg scale was used to
162 measure rating of perceived exertion (RPE) in the final minute of each stage and heart rate
163 (HR) was measured continuously (Polar Electro, Kempele, Finland). Participants signaled to
164 the experimenter if, mid-stage, they could only complete one further minute of exercise, at
165 which point a final 60-s gas sample was collected. Standardized verbal encouragement was
166 provided throughout the RAMP and the test was terminated at volitional exhaustion or when
167 cadence dropped by 5 $\text{revs}\cdot\text{min}^{-1}$ following an initial warning.

168

169 Expired gas samples were analyzed for O_2 and CO_2 concentrations using an automated gas
170 analyzer (Hitech GIR 250, Luton, UK), which was calibrated prior to each test using certified
171 gases of known composition and volume. Total volumes expired were determined using a dry

172 gas meter (Harvard Apparatus, Edenbridge, UK) and the temperatures of expired gases were
173 measured with a digital thermometer (Edale Instruments Ltd., Cambridge, UK). The $\dot{V}O_{2peak}$
174 was identified as the highest $\dot{V}O_2$ value recorded throughout the test and maximal aerobic
175 power (MAP) was defined as the highest average power output maintained for 1 min during
176 the RAMP. The MAP was used to determine the work rate for the cycle section of the two
177 simulated triathlon trials, which was fixed at 75% of MAP based on previous reports relating
178 to OD triathlon (Hue et al. 1997; Delextrat et al. 2005).

179

180 **Simulated Olympic-distance triathlons**

181

182 Following the preliminary testing, two simulated OD triathlon trials were performed in a
183 random order and a single-blind manner. Participants consumed either a 2:1
184 maltodextrin:fructose (CHO) mix based on the protocol of Currell and Jeukendrup (2008),
185 providing $1.2 \text{ g} \cdot \text{min}^{-1}$ of maltodextrin + $0.6 \text{ g} \cdot \text{min}^{-1}$ of fructose, or a sugar-free, fruit-flavored
186 placebo (PLA), as detailed in Table 1. The solutions were mixed in a plastic jug using cold
187 tap water and decanted into an opaque 1-L sports bottle that was individually marked for each
188 25% dose. Participants matched their food consumption and low-intensity training load and
189 avoided alcohol the day before each trial. They arrived at the testing venue on the morning of
190 the trial having abstained from caffeine and eaten a pre-race breakfast of choice that was
191 replicated for both trials.

192

193 INSERT TABLE 1 ABOUT HERE

194

195 Testing began with the standardized swimming WU followed by 2 min of rest and the
196 simulated race ensued immediately. The pace of the 1500-m swim was fixed to within $\pm 5\%$

197 of the STT to ensure a constant pace across both trials. This was achieved by the
198 experimenter giving visual signals after every 100 m advising the participant to slow down,
199 speed up or continue at the same speed. A submerged kickboard indicated the final 100 m.
200 Following the 1500-m swim there was a 3-min transition period before the commencement of
201 the cycle section (Delextrat et al. 2005).

202

203 The cycle section was conducted on poolside and a standing floor fan was used to provide a
204 cooling effect. The fan was positioned facing the cycle ergometer ~ 1 m in front of the
205 participant and the speed of the air flow was ~ 2.5 m·s⁻¹. Participants cycled at 75% of MAP
206 maintaining a cadence of 85 revs·min⁻¹ for a duration that approximated 40 km based on the
207 following equation proposed by Nevill et al. (2006):

208

$$209 \text{ Cycle speed (km}\cdot\text{h}^{-1}\text{)} = 5.1 \times (\text{MAP [W]})^{0.54} \times (\text{body mass [kg]})^{-0.26} \quad [1]$$

210

211 Therefore:

212

$$213 \text{ Cycle duration (min)} = (40 / \text{cycle speed [km}\cdot\text{h}^{-1}\text{)}) \times 60 \quad [2]$$

214

215 Two minutes prior to completing every 25% (i.e., ~ 10 km) of the cycle duration participants
216 ingested 25% of their total fluid volume, which was calculated as:

217

$$218 \text{ Total fluid volume (mL)} = (1.8 \text{ g}\cdot\text{min}^{-1} \times \text{cycle duration [min]}) / 0.144 \quad [3]$$

219

220 In the CHO trial the carbohydrate (115 ± 10 g) was provided in a solution at a concentration
221 of 14.4%, which provided 808 ± 81 mL of fluid, and in the PLA trial the sugar-free, fruit-

222 flavored drink was matched to taste with approximately one part concentrate to three parts
223 water. Fluid consumption was confined to the cycle section, as this has been recognized as
224 the best opportunity to feed during OD triathlon events (Jeukendrup et al. 2005).

225

226 After every 12.5% (i.e., ~ 5 km) of the cycle duration a fingertip blood sample was collected
227 and kept on ice until the end of the trial. Immediately after each trial the blood samples were
228 analyzed for blood glucose ([GLU]) and lactate ([LAC]) concentrations using an automated
229 blood analyzer (YSI 2300 STAT plus, YSI Ltd., Fleet, UK). The HR, RPE and perceived
230 stomach upset (which was assessed using an adapted RPE scale to rate the level of
231 discomfort) were also recorded after every 12.5% of the cycle duration. At the end of the
232 cycle section participants were given a further 3-min transition period to prepare for the run.

233

234 Time and HR data were collected but concealed during the RTT and participants were
235 followed closely throughout the run by a cycling researcher providing standardized
236 encouragement. In order to avoid interference with the collection of ecologically valid
237 performance data, no further physiological measures were made during the RTT. A perceived
238 stomach upset rating was collected immediately after the RTT and a final blood sample was
239 collected 3 min into the recovery period.

240

241 **Statistical Analysis**

242

243 The Statistical Package for the Social Sciences (SPSS) was used to perform statistical
244 procedures and an alpha level of $P < 0.05$ was accepted for significance. Differences in
245 [GLU], [LAC], HR, RPE and perceived stomach upset throughout the cycle section were
246 analyzed using a two-way (time x trial) analysis of variance (ANOVA) with repeated

247 measures. The Greenhouse Geisser correction was used for $\epsilon < 0.75$, while the Huynh-
248 Feldt correction was adopted for less severe asphericity (> 0.75). Normality was checked
249 using the Shapiro-Wilk test and differences between trials were localized using pair-wise
250 comparisons with a Bonferroni adjustment. Paired t-tests were used to compare STT and RTT
251 times, average HR during the run and post-run [GLU], [LAC] and perceived stomach upset
252 data between the two trial conditions. A Wilcoxon Signed Rank Test was used when data
253 were not normally distributed. The effect size (ES) for the change in run time was calculated
254 using the SD of the PLA group, with threshold values for a small, moderate and large ES of
255 0.2, 0.5 and 0.8, respectively (Vincent 2005). Descriptive statistics are expressed as mean \pm
256 SD and tests of difference are reported as mean \pm SEM.

257

258 **RESULTS**

259

260 **Preliminary testing**

261

262 The STT time was 24 min 51 s \pm 3 min 27 s, which resulted in required 100-m split times
263 during the simulated triathlons (i.e., \pm 5%) of 1 min 34 s \pm 13 s to 1 min 44 s \pm 14 s. The
264 cycling $\dot{V}O_{2peak}$ was 4.2 \pm 0.6 L \cdot min⁻¹ (62.8 \pm 9.3 mL \cdot kg⁻¹ \cdot min⁻¹) and MAP was 305 \pm 49 W,
265 which resulted in required cycle durations for the 40-km cycle section (calculated from
266 equations [1] and [2]) of 63 min 54 s \pm 5 min 18 s.

267

268 **Main trials: swim section**

269

270 All participants completed the 1500-m swim section of both simulated triathlons within $\pm 5\%$
271 of their individual STT time, as required, and swim times did not differ between the CHO and
272 PLA conditions ($P = 0.546$).

273

274 **Main trials: cycle section**

275

276 The poolside air temperature was $27.1 \pm 1.4^\circ\text{C}$ and did not differ between trials ($P = 0.956$).
277 Where the prescribed cycling power output could not be maintained (this occurred for two of
278 the 10 participants), the resistance was reduced and these modifications were replicated
279 during the second trial such that all participants could cycle for their calculated duration. The
280 HR, RPE and perceived stomach upset data recorded mid-way through and at the end of the
281 cycle section are displayed Table 2. There were no differences between trials for any of the
282 three variables ($P > 0.05$). The [GLU] changed over time and was significantly higher in the
283 CHO trial from ~ 15 km (i.e., 37.5% of the cycle duration) compared with the PLA trial ($P <$
284 0.001 ; Fig. 1a). The [LAC] did not change over time ($P = 0.097$) but was significantly higher
285 in the CHO trial compared with the PLA trial after 50.0%, 62.5% and 100.0% of the cycle
286 duration ($P < 0.05$; Fig. 1b).

287

288 INSERT TABLE 2 ABOUT HERE

289

290 INSERT FIGURE 1 ABOUT HERE

291

292 **Main trials: run section**

293

294 The outside air temperature during the RTT ($15.9 \pm 7.8^{\circ}\text{C}$) did not differ between trials ($P =$
295 0.917). The RTT was $4.0 \pm 1.3\%$ ($1 \text{ min } 40 \text{ s} \pm 34 \text{ s}$) faster ($\text{ES} = 0.40$) during the CHO trial
296 compared with the PLA trial, with run times of $38 \text{ min } 43 \text{ s} \pm 1 \text{ min } 10 \text{ s}$ and $40 \text{ min } 22 \text{ s} \pm 1$
297 $\text{min } 18 \text{ s}$, respectively ($P = 0.010$; Fig. 2). Mean HR during the RTT (available for $n = 5$
298 only) was 171 ± 3 and $164 \pm 3 \text{ beats}\cdot\text{min}^{-1}$ for the CHO and PLA trials, respectively ($P =$
299 0.149). Post-run [GLU] remained higher in the CHO trial compared with PLA ($P = 0.007$;
300 Fig. 1a) while post-run [LAC] ($P = 0.067$; Fig. 1b) and perceived stomach upset ($P = 0.742$;
301 Table 2) were not different between groups.

302

303 INSERT FIGURE 2 ABOUT HERE

304

305 **DISCUSSION**

306

307 The aim of the present study was to investigate the effects of ingesting a high-dose
308 carbohydrate solution during cycling on subsequent running performance within the context
309 of a simulated OD triathlon. Consistent with the hypothesis, running performance during the
310 final section of the triathlon was significantly improved following ingestion of carbohydrate
311 during the preceding cycling section compared with a placebo. In real-world terms, a 100-s
312 improvement would have moved the second-placed male and female amateur athletes from
313 silver- to gold-medal positions in the 2010 World Age-Group Championships in the 20 – 24
314 yr category (International Triathlon Union), which is the age-group category that seven of the
315 10 participants in the current study would have competed in.

316

317 **Performance responses**

318

319 The primary finding of this investigation is contrary to the only other study that has examined
320 carbohydrate ingestion during an OD triathlon (Millard-Stafford et al. 1990), in which
321 performance was not significantly improved. Since Millard-Stafford et al. (1990) provided
322 carbohydrate at a rate of $\sim 0.7 \text{ g}\cdot\text{min}^{-1}$, compared with $1.8 \text{ g}\cdot\text{min}^{-1}$ in the present study, it may
323 be that the quantity of carbohydrate required to elicit statistically significant improvements in
324 performance is greater than that which has been shown to produce some degree of ergogenic
325 effect during single-discipline events. Despite the unique multi-disciplinary challenge
326 presented by triathlon, it appears that the recommendation for carbohydrate ingestion can be
327 applied as for other single-discipline endurance events.

328

329 While a high carbohydrate dose is suggested here as a potential explanation for the improved
330 run performance, this reasoning requires further specific examination to eliminate other
331 possibilities. For example, additional methodological differences exist between the present
332 study and that conducted by Millard-Stafford et al. (1990). These include environmental
333 temperature differences (the earlier experiment was completed in the heat, at a dry bulb
334 temperature of $30.0 \pm 0.6^\circ\text{C}$), a mixture of sexes used within the present study and different
335 pre-trial eating strategies, whereby a breakfast of choice was used in the present study to
336 more accurately simulate race-day conditions. Although endurance exercise performed in a
337 post-prandial state appears to affect metabolic responses when compared with overnight
338 fasting, however, 10-km run time does not appear to be affected (Whitley et al. 1998). The
339 current study also used a standardized relative cycling intensity as opposed to a free-paced
340 cycle section. While a fixed power output was used during the cycle section to control the
341 comparison of the subsequent run performance between trials, it would be useful to
342 complement these data with future studies examining carbohydrate ingestion during a fully
343 self-paced (i.e., race-specific) OD triathlon.

344

345 **Metabolic responses**

346

347 Higher concentrations of blood glucose were expected in the CHO trial compared with the
348 PLA trial and the current results are in agreement with previous findings in relation to OD
349 triathlon (Millard-Stafford et al. 1990). While measurements necessary to evaluate the
350 specific derivation of substrate metabolism were not included in the current study, as it was
351 considered a priority to provide an externally valid assessment of performance, a number of
352 possibilities could explain the improved 10-km run time. The higher [GLU] following
353 carbohydrate consumption may have led to a direct increase in the rate of carbohydrate
354 oxidation by the working muscles, which has previously been shown to improve exercise
355 performance and delay the onset of fatigue (Coyle et al. 1986; Coggan and Coyle 1989).
356 However, since this explanation is speculative and the specific mechanisms by which
357 carbohydrate ingestion improves performance are currently unclear (Karelis et al. 2010),
358 further research is required to fully understand the enhanced performance observed in the
359 present study.

360

361 **Subjective responses**

362

363 Considering the central mechanisms potentially associated with carbohydrate sensing and
364 ingestion (Meeusen et al. 2006; Jeukendrup and Chambers 2010), the CHO trial may have
365 been expected to elicit a lower perception of exertion throughout the cycle section compared
366 with the PLA trial. However, no differences in RPE were identified between the two trials.
367 This finding was combined with an anecdotal, post-facto inability of participants to
368 successfully guess which trial they had just participated in, with only two participants

369 confidently identifying the CHO solution. Perhaps more notable than RPE, at least from a
370 practical perspective, perceived stomach upset did not differ between trials throughout the
371 cycle section or at the end of the run. Due to common complaints among racing triathletes of
372 gastro-intestinal discomfort from fluid consumption, particularly when carbohydrate
373 concentrations are high (Jeukendrup et al. 2005; Bentley et al. 2008), this finding was
374 unexpected. With no additional gastro-intestinal discomfort, a high-concentration
375 carbohydrate solution would appear to be beneficial for competitive triathletes as it reduces
376 the required volume of fluids, which may be advantageous when running after cycling. While
377 it is possible that intestinal carbohydrate absorption was enhanced with the use of multiple
378 types of carbohydrate, this remains to be examined.

379

380 **Strengths and limitations of the study**

381

382 Despite the majority of investigations recruiting male-only groups when examining the
383 effects of carbohydrate metabolism on exercise, four of the 10 participants in the present
384 study were female. Although avoidance of females is usually due to perceived difficulties
385 associated with controlling for the menstrual cycle, evidence regarding the effects of
386 menstrual phase on metabolism and performance appears equivocal (Hornum et al. 1997;
387 Hackney 1999; Bailey et al. 2000; Campbell et al. 2001). Given that an effect of treatment
388 was observed in the female participants (i.e., a 3.7% performance improvement) reflective of
389 that observed for males (i.e., a 4.1% performance improvement), any error variance that was
390 introduced by menstrual variability appears insufficient to have masked the effect of
391 treatment in this instance.

392

393 **Conclusion**

394

395 The present study has shown that a 2:1 maltodextrin:fructose solution ingested at a rate of 1.8
396 $\text{g}\cdot\text{min}^{-1}$ and mixed to a concentration of 14.4% significantly improves running performance
397 within a simulated OD triathlon when ingested throughout the cycle section. This is the first
398 study to show significant improvements in any measure of triathlon performance with
399 carbohydrate ingestion. Importantly, the relatively concentrated carbohydrate solution was
400 not associated with an increase in gastro-intestinal discomfort compared with a placebo. As
401 such, the findings of the current study advocate ingestion of $1.2 \text{ g}\cdot\text{min}^{-1}$ of maltodextrin +
402 $0.6 \text{ g}\cdot\text{min}^{-1}$ of fructose at 14.4% concentration as opposed to non-caloric fluid throughout the
403 cycle section of OD triathlon for the purpose of enhancing subsequent 10-km run
404 performance.

405

406 **ACKNOWLEDGEMENTS**

407

408 The authors would like to express their gratitude to the participants involved in the study for
409 their commitment and cooperation. The authors have no conflicts of interest in relation to this
410 work and no funding was received to carry out the investigation.

411

412

413 **REFERENCES**

414

415 Bailey, S.P., Zacher, C.M., and Mittleman, K.D. 2000. Effect of menstrual cycle phase on
416 carbohydrate supplementation during prolonged exercise to fatigue. *J Appl Physiol.*
417 **88**(2): 690-697.

418 Bentley, D.J., Cox, G.R., Green, D., and Laursen, P.B. 2008. Maximising performance in
419 triathlon: applied physiological and nutritional aspects of elite and non-elite
420 competitions. *J Sci Med Sport.* **11**(4): 407-416.

421 Bentley, D.J., Millet, G.P., Vleck, V.E., and McNaughton, L.R. 2002. Specific aspects of
422 contemporary triathlon: implications for physiological analysis and performance.
423 *Sports Med.* **32**(6): 345-359.

424 Bernard, T., Vercruyssen, F., Grego, F., Hausswirth, C., Lepers, R., Vallier, J.M., et al. 2003.
425 Effect of cycling cadence on subsequent 3 km running performance in well trained
426 triathletes. *Br J Sports Med.* **37**(2): 154-159.

427 Campbell, S.E., Angus, D.J., and Febbraio, M.A. 2001. Glucose kinetics and exercise
428 performance during phases of the menstrual cycle: effect of glucose ingestion. *Am J*
429 *Physiol Endocrinol Metab.* **281**(4): E817-E825.

430 Carter, J., Jeukendrup, A.E., Mundel, T., and Jones, D.A. 2003. Carbohydrate
431 supplementation improves moderate and high-intensity exercise in the heat. *Pflügers*
432 *Arch.* **446**(2): 211-219.

433 Coggan, A.R., and Coyle, E.F. 1989. Metabolism and performance following carbohydrate
434 ingestion late in exercise. *Med Sci Sports Exerc.* **21**(1): 59-65.

435 Coyle, E.F., Coggan, A.R., Hemmert, M.K., and Ivy, J.L. 1986. Muscle glycogen utilization
436 during prolonged strenuous exercise when fed carbohydrate. *J Appl Physiol.* **61**(1):
437 165-172.

438 Currell, K., and Jeukendrup, A.E. 2008. Superior endurance performance with ingestion of
439 multiple transportable carbohydrates. *Med Sci Sports Exerc.* **40**(2): 275-281.

440 Delextrat, A., Brisswalter, J., Hausswirth, C., Bernard, T., and Vallier, J. 2005. Does prior
441 1500-m swimming affect cycling energy expenditure in well-trained triathletes? *Can J*
442 *Appl Physiol.* **30**(4): 392-403.

443 Hackney, A.C. 1999. Influence of oestrogen on muscle glycogen utilization during exercise.
444 *Acta Physiol Scand.* **167**(3): 273-274.

445 Hausswirth, C., and Brisswalter, J. 2008. Strategies for improving performance in long
446 duration events: Olympic distance triathlon. *Sports Med.* **38**(11): 881-891.

447 Hausswirth, C., Vallier, J., Lehenhaff, D., Brisswalter, J., Smith, D., Millet, G., et al. 2001.
448 Effect of two drafting modalities in cycling on running performance. *Med Sci Sports*
449 *Exerc.* **33**(3): 485-492.

450 Hornum, M., Cooper, D.M., Brasel, J.A., Bueno, A., and Sietsema, K.E. 1997. Exercise-
451 induced changes in circulating growth factors with cyclic variation in plasma estradiol
452 in women. *J Appl Physiol.* **82**(6): 1946-1951.

453 Hue, O., Le Gallais, D., Chollet, D., Boussana, A., and Préfaut, C. 1997. The influence of
454 prior cycling on biomechanical and cardiorespiratory response profiles during running
455 in triathletes. *Eur J Appl Physiol.* **77**(1): 98-105.

456 International Triathlon Union. Triathlon Budapest. Available from
457 <http://www.triathlonbudapest.com/> [accessed 24 August 2011].

458 Jentjens, R.L.P.G., and Jeukendrup, A.E. 2005. High rates of exogenous carbohydrate
459 oxidation from a mixture of glucose and fructose ingested during prolonged cycling
460 exercise. *Br J Nutr.* **93**(4): 485-492.

461 Jentjens, R.L.P.G., Moseley, L., Waring, R.H., Harding, L.K., and Jeukendrup, A.E. 2004.
462 Oxidation of combined ingestion of glucose and fructose during exercise. *J Appl*
463 *Physiol.* **96**(4): 1277-1284.

464 Jeukendrup, A.E., and Chambers, E.S. 2010. Oral carbohydrate sensing and exercise
465 performance. *Curr Opin Clin Nutr Metab Care.* **13**(4): 447-451.

466 Jeukendrup, A.E., and Jentjens, R.L.P.G. 2000. Oxidation of carbohydrate feedings during
467 prolonged exercise: current thoughts, guidelines and directions for future research.
468 *Sports Med.* **29**(6): 407-424.

469 Jeukendrup, A.E., Jentjens, R.L.P.G., and Moseley, L. 2005. Nutritional considerations in
470 triathlon. *Sports Med.* **35**(2): 163-181.

471 Karelis, A.D., Smith, J.E.W., Passe, D.H., and Péronnet, F. 2010. Carbohydrate
472 administration and exercise performance: what are the potential mechanisms
473 involved? *Sports Medicine.* **40**(9): 747-763.

474 Meeusen, R., Watson, P., Hasegawa, H., Roelands, B., and Piacentini, M.F. 2006. Central
475 fatigue: the serotonin hypothesis and beyond. *Sports Med.* **36**(10): 881-909.

476 Millard-Stafford, M., Sparling, P.B., Roskopf, L.B., Hinson, B.T., and Dicarlo, L.J. 1990.
477 Carbohydrate-electrolyte replacement during a simulated triathlon in the heat. *Med*
478 *Sci Sports Exerc.* **22**(5): 621-628.

479 Millet, G.P., and Vleck, V.E. 2000. Physiological and biomechanical adaptations to the cycle
480 to run transition in Olympic triathlon: review and practical recommendations for
481 training. *Br J Sports Med.* **34**(5): 384-390.

482 Nevill, A., Jobson, S., Davison, R., and Jeukendrup, A. 2006. Optimal power-to-mass ratios
483 when predicting flat and hill-climbing time-trial cycling. *Eur J Appl Physiol.* **97**(4):
484 424-431.

485 Peeling, P., and Landers, G. 2009. Swimming intensity during triathlon: a review of current
486 research and strategies to enhance race performance. *J Sports Sci.* **27**(10): 1079-1085.

487 Peeling, P.D., Bishop, D.J., and Landers, G.J. 2005. Effect of swimming intensity on
488 subsequent cycling and overall triathlon performance. *Br J Sports Med.* **39**(12): 960-
489 964.

490 Reilly, T., and Brooks, G.A. 1982. Investigation of circadian rhythms in metabolic responses
491 to exercise. *Ergonomics.* **25**(11): 1093 - 1107.

492 Suriano, R., and Bishop, D. 2010. Combined cycle and run performance is maximised when
493 the cycle is completed at the highest sustainable intensity. *Eur J Appl Physiol.* **110**(4):
494 753-760.

495 Suriano, R., Vercruyssen, F., Bishop, D., and Brisswalter, J. 2007. Variable power output
496 during cycling improves subsequent treadmill run time to exhaustion. *J Sci Med
497 Sport.* **10**(4): 244-251.

498 Temesi, J., Johnson, N.A., Raymond, J., Burdon, C.A., and O'Connor, H.T. 2011.
499 Carbohydrate ingestion during endurance exercise improves performance in adults. *J
500 Nutr.* **141**(5): 890-897.

501 Tsintzas, K., and Williams, C. 1998. Human muscle glycogen metabolism during exercise:
502 effect of carbohydrate supplementation. *Sports Med.* **25**(1): 7-23.

503 Tsintzas, K., Williams, C., Wilson, W., and Burrin, J. 1996. Influence of carbohydrate
504 supplementation early in exercise on endurance running capacity. *Med Sci Sports
505 Exerc.* **28**(11): 1373-1379.

506 Vercruyssen, F., Brisswalter, J., Hausswirth, C., Bernard, T., Bernard, O., and Vallier, J.M.
507 2002. Influence of cycling cadence on subsequent running performance in triathletes.
508 *Med Sci Sports Exerc.* **34**(3): 530-536.

509 Vercruyssen, F., Hausswirth, C., Smith, D., and Brisswalter, J. 2001. Effect of exercise
510 duration on optimal pedaling rate choice in triathletes. *Can J Appl Physiol.* **26**(1): 44-
511 54.

512 Vercruyssen, F., Suriano, R., Bishop, D., Hausswirth, C., and Brisswalter, J. 2005. Cadence
513 selection affects metabolic responses during cycling and subsequent running time to
514 fatigue. *Br J Sports Med.* **39**(5): 267-272.

515 Vincent, W.J. 2005. *Statistics in Kinesiology.* Human Kinetics, Champaign, IL.

516 Whitley, H.A., Humphreys, S.M., Campbell, I.T., Keegan, M.A., Jayanetti, T.D., Sperry,
517 D.A., et al. 1998. Metabolic and performance responses during endurance exercise
518 after high-fat and high-carbohydrate meals. *Journal of Applied Physiology.* **85**(2):
519 418-424.

520 Wright, D.A., Sherman, W.M., and Dernbach, A.R. 1991. Carbohydrate feedings before,
521 during, or in combination improve cycling endurance performance. *J Appl Physiol.*
522 **71**(3): 1082-1088.

523

524

525 **TABLES**

526

527 Table 1: Details of the two drinks provided during the maltodextrin + fructose (CHO) and
 528 placebo (PLA) trials

CHO	Product: EnergySource Fresh Citrus flavor, H5 Ltd., Leicestershire, UK Ingredients: Maltodextrin, Fructose, Natural Flavors (Spray Dried Fruit Juice: Orange, Lemon, Lime), Citric Acid, Tri Sodium Citrate, Sodium Chloride, Potassium Citrate Nutritional content (per 100 g): 384 kcal, Protein 0 g, Carbohydrate 96 g (Maltodextrin 64 g, Fructose 32 g), Fat 0 g, Fiber 0 g Electrolyte content (per 100 g): Sodium 0.7 g, Potassium 0.7 g
<hr/>	
PLA	Product: Robinsons Orange & Mango No Added Sugar, Britvic Soft Drinks Ltd, Chelmsford, UK Ingredients: Water, Orange Fruit from Concentrate (11%), Mango Juice from Concentrate (1%), Citric Acid, Acidity Regulator (Sodium Citrate), Flavouring, Sweeteners (Aspartame, Saccharin), Preservatives (Potassium Sorbate, Sodium Metabisulphite), Stabiliser (E466), Colours (Anthocyanins, Beta-carotene), Vitamins (Niacin, Pantothenic Acid, B6, B12) Nutritional content (per 100 mL): 8 kcal, Protein 0.2 g, Carbohydrate 0.7 g (of which sugars 0.7 g), Fat 0 g, Fiber 0.3 g Electrolyte content (per 100 mL): Sodium 0.1 g

529 Table 2: Mean \pm SEM heart rate (HR), rating of perceived exertion (RPE) and perceived
 530 stomach upset during the cycle section and following the run section within the maltodextrin
 531 + fructose (CHO) and placebo (PLA) trials

		% of cycle duration		
		50%	100%	Post-run
HR (beats·min ⁻¹)	CHO	143 \pm 6	142 \pm 5	-
	PLA	144 \pm 4	142 \pm 4	-
RPE	CHO	14 \pm 1	14 \pm 1	-
	PLA	14 \pm 1	15 \pm 1	-
Perceived stomach upset	CHO	10 \pm 1	11 \pm 1	13 \pm 1
	PLA	9 \pm 1	10 \pm 1	12 \pm 1

532 No significant differences between CHO and PLA ($P > 0.05$)

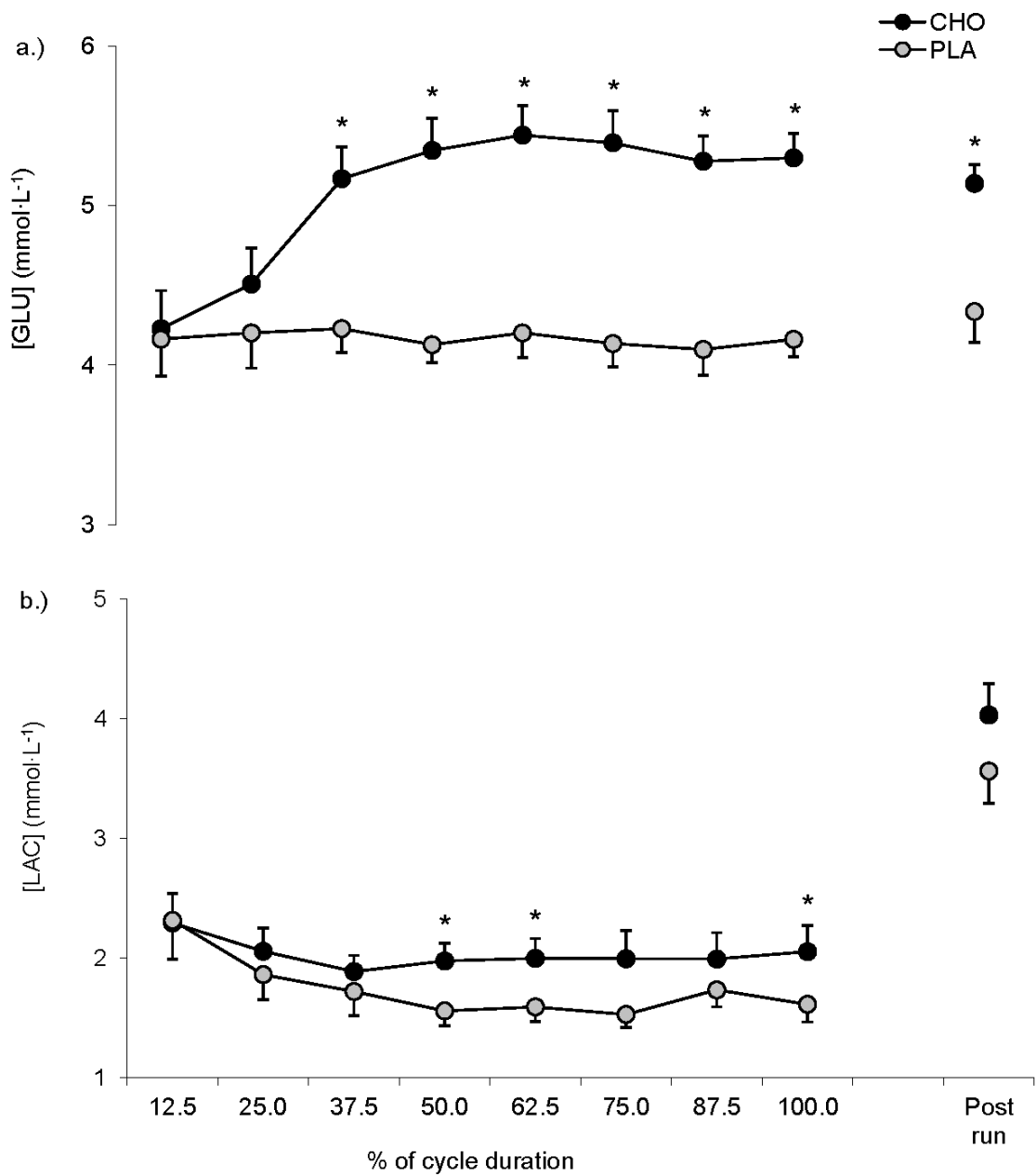
533

534 **FIGURES**

535

536 Figure 1: Mean \pm SEM a.) blood glucose concentration ([GLU]) and b.) blood lactate
537 concentration ([LAC]) during the cycle section and following the run section within the
538 maltodextrin + fructose (CHO) and placebo (PLA) trials. * Significantly different from the
539 PLA trial ($P < 0.05$)

540

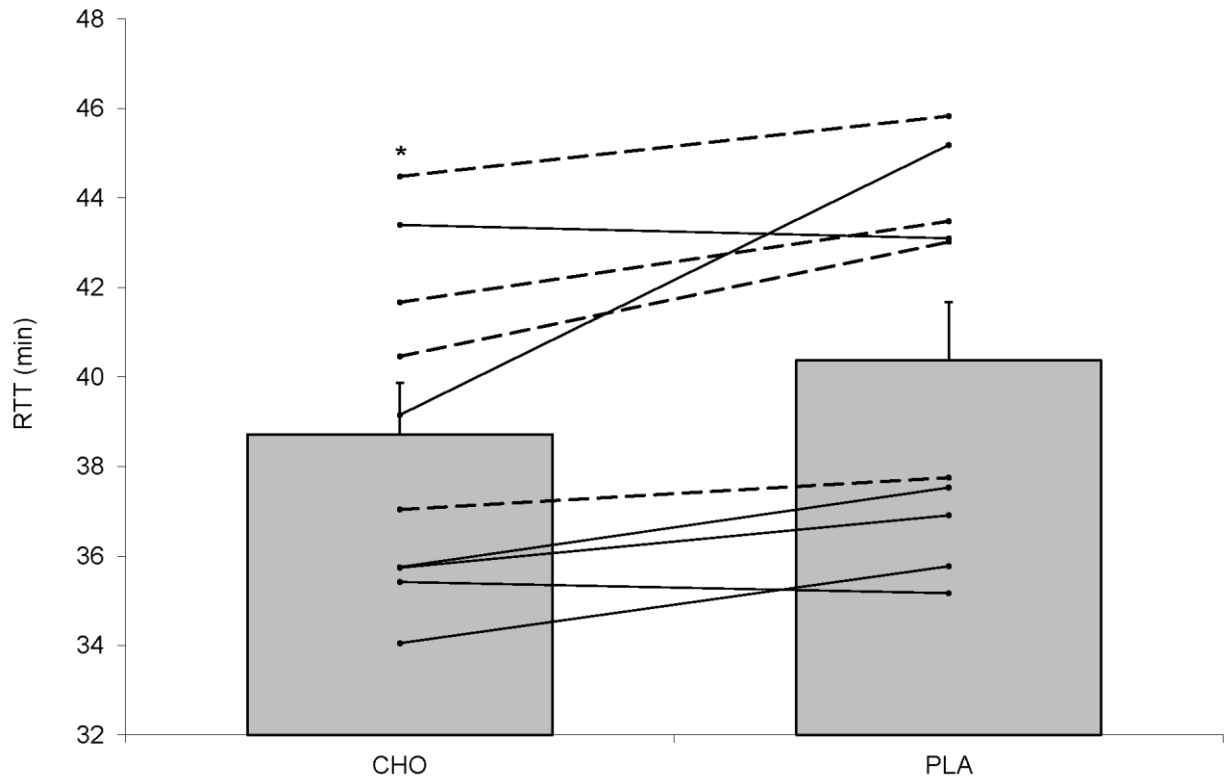


541

542

543 Figure 2: Run time-trial (RTT) performance within the maltodextrin + fructose (CHO) and
544 placebo (PLA) trials; male participants marked with solid lines and females with dashed
545 lines. * Significantly different from the PLA trial ($P < 0.05$)

546



547