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**Perception of carbohydrate availability augments high-intensity intermittent exercise capacity under sleep-low train low conditions**

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**Running title:** Perception of CHO and train-low

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**Abstract**

We tested the hypothesis that perception of carbohydrate (CHO) availability augments exercise capacity in conditions of reduced CHO availability. Nine males completed a sleep-low train-model comprising evening glycogen depleting cycling followed by an exhaustive cycling protocol the next morning in the fasted state (30 minutes steady-state, SS, at 95% lactate threshold followed by 1-min intervals at 80% peak power output until exhaustion). After the evening depletion protocol and prior to sleeping, subjects consumed 1) a known CHO intake of 6 g.kg<sup>-1</sup> body mass (TRAIN HIGH), 2) a perceived comparable CHO intake but 0 g.kg<sup>-1</sup> body mass (PERCEPTION) or a known train-low condition of 0 g.kg<sup>-1</sup> body mass (TRAIN LOW). **The TRAIN HIGH and PERCEPTION trials were conducted double blind. During SS, average** blood glucose and CHO oxidation were significantly higher in TRAIN HIGH (4.01 ± 0.56 mmol.L<sup>-1</sup>; 2.17 ± 0.70 g.min<sup>-1</sup>) versus both PERCEPTION (3.30 ± 0.57 mmol.L<sup>-1</sup>; 1.69 ± 0.64 g.min<sup>-1</sup>, **P<0.05**) and TRAIN LOW (3.41 ± 0.74 mmol.L<sup>-1</sup>; 1.61 ± 0.59 g.min<sup>-1</sup>, **P<0.05**). Exercise capacity was significantly different between all pairwise comparisons (**P<0.05**) where TRAIN LOW (8 ± 8 min) < PERCEPTION (12 ± 6 min) < TRAIN HIGH (22 ± 9 min). Data demonstrate that perception of CHO availability augments **high-intensity intermittent** exercise capacity under sleep-low, train-low conditions though perception does not restore exercise capacity to that of CHO consumption. Such data have methodological implications for future research designs and may also have practical applications for athletes who deliberately practice elements of training in CHO restricted states.

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**Keywords:** placebo, carbohydrate, train-low, capacity

67

## 68 Introduction

69 In addition to its well-documented role as an energy source, it is now recognised that the  
70 glycogen granule exerts regulatory roles in modulating skeletal muscle cell signalling and  
71 transcriptional responses to acute exercise sessions (Bartlett et al., 2015; Hearn et al., 2018).  
72 Accordingly, deliberately commencing and/or recovering from training sessions with reduced  
73 CHO availability (the so-called train-low paradigm) increases markers of mitochondrial  
74 biogenesis (Hansen et al., 2005; Yeo et al., 2008; Morton et al., 2009) and both whole body  
75 and intramuscular lipid oxidation (Yeo et al., 2008; Hulston et al., 2010). In some instances,  
76 both exercise capacity (Hansen et al., 2005) and exercise performance (Cochran et al., 2015;  
77 Marquet et al., 2016a,b) have also been augmented with short-term (i.e. 3-10 weeks) train-  
78 low approaches though it is acknowledged that this is not a consistent finding amongst  
79 chronic training studies. On this basis, it has therefore been suggested that CHO should be  
80 adjusted day-by-day and meal-by-meal in accordance with the goals of both maximising  
81 training quality (i.e. ability to sustain the desired workload) and skeletal muscle adaptations  
82 (Impey et al., 2018).

83 Whilst there are multiple research designs used to practically achieve train-low  
84 conditions (i.e. twice per day training protocols, fasted training and or withholding CHO in  
85 the recovery period from acute exercise), the 'sleep-low, train-low' model has emerged as a  
86 particularly potent strategy for which to prolong the period of CHO restriction (Bartlett et al.,  
87 2013; Lane et al., 2015). In this approach, participants perform an evening training session,  
88 restrict CHO during overnight recovery, and then complete a fasted training session on the  
89 following morning. The accumulative time with reduced muscle glycogen could therefore  
90 extend to 12–14 h depending on the timing and duration of the training sessions and sleep  
91 period. When performed chronically, Marquet et al. (2016a,b) observed that 1–3 weeks of  
92 sleep-low training in elite triathletes and cyclists improves cycling efficiency (3.1%), 20 km

93 cycling time-trial performance (3.2%) and 10 km running performance (2.9%) compared with  
94 traditional train-high approaches.

95         Despite the aforementioned findings, an obvious limitation of the sleep-low, train-low  
96 model is that exercise capacity is likely to be significantly impaired during the morning  
97 training session. Indeed, we recently observed that stepwise reductions in pre-exercise  
98 muscle glycogen concentration  $\sim 100 \text{ mmol.kg}^{-1}$  dry wt (as achieved by the sleep low model)  
99 impaired morning exercise capacity at 80% peak power output (PPO) by  $\sim 20$  to 50% (Hearris  
100 et al., 2019). Nonetheless, we acknowledged that lack of blinding between conditions  
101 (subjects were aware of CHO availability given that whole foods were consumed) may have  
102 influenced subjects' perception of their ability of complete high-intensity workloads. Indeed,  
103 placebo effects of CHO availability have been reported in conditions of CHO feeding before  
104 (Mears et al., 2018) and during exercise (Clark et al., 2000). To the authors' knowledge,  
105 however, the potential placebo effect of CHO availability has not yet been examined under  
106 conditions where exercise is commenced with sub-optimal muscle glycogen concentration.

107         With this in mind, the aim of the present study was to test the hypothesis that  
108 perception of CHO availability augments exercise capacity. To this end, we adopted a sleep-  
109 low, train-low model of CHO restriction where recreationally active males commenced an  
110 exhaustive morning training session under conditions corresponding to a known prior CHO  
111 intake of  $6 \text{ g.kg}^{-1}$  body mass (TRAIN-HIGH), a perceived comparable CHO intake  
112 (PERCEPTION) or a known train-low condition during which no CHO was consumed prior  
113 to sleeping (TRAIN-LOW). We specifically hypothesised that perception of CHO availability  
114 would improve morning exercise capacity compared to known train-low conditions but that  
115 perception would not restore exercise capacity to that of true train-high conditions.

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## 119 **Methods**

120

121 **Subjects.** Nine recreationally active males who regularly engaged in exercise training  
122 (running, cycling, and intermittent sport) between 3-6 times per week volunteered to  
123 participate in the study (mean  $\pm$  SD: age,  $25 \pm 8$  years; body mass,  $71.6 \pm 8.5$  kg; height,  $1.78$   
124  $\pm 0.06$  m;  $VO_{2peak}$ ,  $55.3 \pm 8.3$  ml.kg<sup>-1</sup>.min<sup>-1</sup>; peak power output (PPO)  $331 \pm 41$  watts). All  
125 subjects gave written and informed consent after details of the study procedures were  
126 explained. No subject had a history of smoking, cardiovascular, or metabolically related  
127 disease and none were under pharmacological treatment during the study. All subjects  
128 refrained from strenuous exercise and alcohol for at least 24 h before each trial. The study  
129 was approved by the Ethics Committee of Liverpool John Moores University.

130 **Experimental Design.** In a randomized, repeated measures design (and after appropriate  
131 baseline testing and familiarization), subjects performed three experimental trials consisting  
132 of a glycogen depleting protocol in the afternoon prior to the main experimental trial the  
133 subsequent morning. At the cessation of the glycogen depleting protocol, subjects consumed  
134 1) a known CHO intake of 6 g.kg<sup>-1</sup> body mass (TRAIN-HIGH), 2) a perceived comparable  
135 CHO intake but 0 g.kg<sup>-1</sup> body mass (PERCEPTION) or a known train-low condition of 0  
136 g.kg<sup>-1</sup> body mass (TRAIN-LOW). **The TRAIN HIGH and PERCEPTION trials were double**  
137 **blind where blinding of these two solutions were performed by the corresponding author who**  
138 **was not present for any of the exhaustive exercise sessions on Day 2 (with the exception of**  
139 **the familiarisation trials).** The following morning subjects arrived at the laboratory in a  
140 fasted state where they then performed a steady-state (SS) (30 min at 95% of **lactate**  
141 **threshold**) cycling exercise protocol followed by a **high-intensity intermittent (HIT)** cycling  
142 protocol to exhaustion (1-min bouts at 80% PPO interspersed with 1-min bouts at 40% PPO).  
143 The primary outcome was exercise capacity during the HIT protocol. Respiratory gas

144 exchange, heart rate (HR), rate of perceived exertion (RPE), and fingertip capillary blood  
145 samples were also obtained at regular intervals during the SS exercise protocol and  
146 immediately following HIT protocol to assess for physiological, metabolic, and perceptual  
147 responses to exercise. An overview of the experimental design is shown in Figure 1. **The**  
148 **participants were informed that the aim of the study was to compare the effects of two CHO**  
149 **drinks (that differed in composition but not quantity of CHO) on overnight recovery and**  
150 **subsequent morning exercise capacity versus a known non-caloric sugar free drink. Upon**  
151 **completion of the study, all subjects performed an exit interview where they were informed**  
152 **they had been deceived in the PERCEPTION trial. Whilst no formal questionnaires were**  
153 **administered, no subject reported that the drinks tasted differently though 3 subjects did**  
154 **report they felt hungrier in the both the TRAIN LOW and PERCEPTION trials.**

155 *Assessment of lactate threshold, lactate turn point,  $VO_{2peak}$  and peak power output.* At least  
156 5-7 days prior to the familiarization (FAM) trial, subjects performed a submaximal  
157 incremental cycling protocol to determine lactate threshold (LT), lactate turn point (LTP),  
158 peak oxygen uptake ( $VO_{2peak}$ ) and peak power output (PPO) on an electronically braked  
159 cycling ergometer (Excalibur Sport; Lode, Groningen, The Netherlands). Following a 5 min  
160 warm up at 75 watts (W) at a self-selected cadence, the submaximal test commenced at 125  
161 W with 25 W increase every 4 min. Twenty  $\mu$ l of fingertip capillary blood samples were  
162 collected in a Biosen capillary tube (EKF Diagnostics, Barleben, Germany) at the end of each  
163 4 min stage. LT (defined as 1 mmol.L<sup>-1</sup> above resting levels) and LTP (defined as the second  
164 inflection point on the lactate curve) were plotted live during the test using Biosen C-Line  
165 lactate analyzer (EKF Diagnostics, Barleben, Germany). Heart Rate (HR) (Polar, F10,  
166 Finland) was **monitored continuously and recorded** during the final 10 seconds of each stage,  
167 along with RPE (Borg, 1973). Respiratory gas exchange was recorded during the final two  
168 minutes of each stage using an online gas analysis system (CPX Ultima, Medgraphics,

169 Minnesota, USA). The submaximal test ended once LTP had been confirmed. Following a 5  
170 min recovery period,  $\text{VO}_{2\text{peak}}$  and PPO were assessed. The test to assess  $\text{VO}_{2\text{peak}}$  and PPO  
171 commenced at 25 W below each subject's individual LT and consisted of 1-min stages with  
172 25 W increments until volitional exhaustion. HR was monitored throughout the test.  $\text{VO}_{2\text{peak}}$   
173 referred to the peak value attained in any 10-second period during the last 60 seconds of data  
174 collection and was supported by verification by two or all the following end point criteria (1)  
175 heart rate with  $10 \text{ b}\cdot\text{min}^{-1}$  of age predicted maximum, (2)  $\text{RER} > 1.1$  and (3) plateau of  
176 oxygen consumption despite increasing workload.

177 **Day 1: Glycogen depletion protocol.** On the afternoon of Day 1, subjects arrived at the  
178 laboratory (~1500 h) to perform an intermittent bout of cycling to volitional fatigue. Subjects  
179 were asked to record and replicate their energy intake in the 24 h period prior to commencing  
180 the glycogen depletion protocol. Following a 5 min warm up at self-selected intensity,  
181 subjects cycled for 2 min at 90% PPO, immediately followed by 2 min at 50% PPO. Once  
182 subjects could no longer maintain  $> 60 \text{ rpm}$ , the interval was decreased to 90 seconds, then to  
183 1 min at 90% PPO. Subjects repeated this work to rest ratio at 80% PPO, 70% PPO, and 60%  
184 PPO and the exercise protocol was terminated once subjects could no longer maintain  $> 60$   
185  $\text{rpm}$  at 60% PPO for 1 min. This protocol has been used previously in our laboratory (Bartlett  
186 et al., 2013; Taylor et al., 2013; Impey et al., 2016) and is a modification of that of Kuipers et  
187 al. (1987) that induces glycogen depletion in both type I and type II fibers. Immediately  
188 following the cessation of glycogen depleting exercise (~1700 h), subjects consumed 30 g of  
189 whey protein isolate (Advanced Whey Isolate, Science in Sport, Nelson, UK) mixed with 250  
190 ml water (in accordance with practical recommendations to promote recovery from  
191 endurance exercise) before adhering to one of three dietary protocols. In the TRAIN HIGH  
192 trial, subjects consumed  $1.2 \text{ g}\cdot\text{kg}^{-1}$  maltodextrin (Cargill Dry Maltodextrin, UK) mixed with  
193 500 ml water sugar free squash (Tesco, Hertfordshire, UK) per hour for 5 hours. In the

194 PERCEPTION trial, subjects adhered to an identical feeding frequency and volume protocol  
195 but consumed a tasted match placebo solution where they were told contained an identical  
196 amount of CHO as that consumed (or to be consumed) in the TRAIN HIGH trial (sugar free  
197 squash, Tesco, Hertfordshire, UK). In the TRAIN LOW trial, subjects consumed the same  
198 placebo solution as the PERCEPTION trial but were told the solution contained no CHO. All  
199 drinks were administered in visually opaque bottles and 2.75 L of fluid was consumed over  
200 the 5-hour recovery period in each trial. **Subjects remained in the laboratory to complete the**  
201 **first 3 h of the recovery protocol before returning to their homes to complete the last 2 h of**  
202 **recovery (subjects were provided with the additional 2 x 500 ml solutions to take home).**  
203 **Subjects also slept at their own home.**

204 **Day 2: Steady state (SS) and HIT exercise capacity test.** Subjects arrived at the laboratory  
205 between 0800 and 0830h the following morning after an overnight fast. Body mass (Seca,  
206 Hamburg, Germany), motivation to train (using a visual analogue scale, VAS, McCormack et  
207 al., 1988), resting blood lactate and blood glucose were initially measured. Subjects then then  
208 completed 30 min SS cycling at 95% of LT. Breath by breath gas analysis (CPX Ultima,  
209 Medgraphics, Minnesota, USA) was measured for 2 min during 8-10 min, 18-20 min, and 28-  
210 30 min and substrate utilization was assessed according to Jeukendrup and Wallis (2005).  
211 Blood glucose and blood lactates samples were obtained at 15 min and 30 min.  
212 Measurements of HR (Polar, F10, Finland) and RPE (Borg, 1973) were recorded at 10 min  
213 intervals during the SS exercise. Following completion of SS exercise, subjects were  
214 provided with 3 min active recovery at 50 W and subsequently commenced the HIT exercise  
215 capacity test consisting of 1 min bouts at 80% PPO interspersed with 1 min bouts at 40%  
216 PPO until volitional exhaustion. A final capillary blood sample was collected at the  
217 termination of the HIT protocol.

218 **Familiarization.** Eight subjects completed the full experimental protocol described above  
219 while adhering to a water only (i.e. no flavoring) familiarization (FAM) condition at least 7  
220 days prior to their first experimental trial (one of the nine subjects withdrew from  
221 familiarization after several minutes of the SS exercise protocol having reported feelings of  
222 muscle soreness). Upon completion of all three experimental trials, we compared each  
223 subject's exercise capacity during the FAM trial and the TRAIN LOW trial and observed no  
224 significant difference, as evidenced by a *t*-test for paired samples (FAM = 5 ± 5 min, PLA =  
225 7 ± 6 min, P=0.25).

226 **Blood analyses.** Blood samples were obtained via finger prick capillary sampling using a 1.8  
227 mm sterile safety-lancet (Sarstedt AG & Co, Nümbrecht, Germany) after sterilization using a  
228 pre-injection medical swab (Medlock Medical Ltd., Oldham). A 20µl blood sample was  
229 collected in a Biosen capillary tube (EKF Diagnostics, Barleben, Germany) and analyzed  
230 using Biosen C-Line for blood glucose and lactate concentrations (EKF Diagnostics,  
231 Barleben, Germany).

232 **Statistical Analysis.** Data were analysed using one or two-way repeated measures general  
233 linear model (GLM) where the within factors were time and condition (TRAIN LOW,  
234 PERCEPTION and TRAIN HIGH). Where significant main effects were found, paired  
235 samples *t*-tests with Bonferroni adjustment for multiple comparisons were performed to  
236 identify differences. In relation to our primary outcome variable of exercise capacity, we also  
237 report uncertainty of outcomes as 95% confidence intervals (95% CI) and make probabilistic  
238 magnitude based-inferences about the true (large sample) values of outcomes by qualifying  
239 the likelihood that the true effect represents a substantial change, according to (Batterham &  
240 Hopkins, 2006). All data in text, tables and figures are expressed as means ± SD with  $P < 0.05$

241 indicating statistical significance. Statistical analyses were performed using Statistics  
242 Package for the Social Sciences (SPSS) for Windows (version 24, SPSS Inc, Chicago, IL).

243

## 244 **Results**

### 245 *Glycogen depletion protocol*

246 There was no difference ( $P=0.71$ ) in time to exhaustion during the glycogen depletion  
247 protocol between the TRAIN HIGH ( $79 \pm 20$  min), PERCEPTION ( $75 \pm 16$  min) or TRAIN  
248 LOW ( $79 \pm 22$  min) trials.

249

### 250 *Physiological and perceptual responses during SS exercise*

251 There was no difference ( $P=0.258$ ) in subjects' motivation to exercise prior to commencing  
252 the SS protocol (TRAIN HIGH  $6.7 \pm 2.7$  cm; PERCEPTION  $6.4 \pm 1.7$  cm; TRAIN LOW  
253  $5.1 \pm 2.1$  cm). Subjects' HR ( $P=0.006$ ) and RPE ( $P<0.001$ ) increased during SS though no  
254 difference was apparent between conditions ( $P=0.299$  and  $0.273$  respectively, see Table 1).

255

### 256 *Metabolic responses during SS exercise and HIT capacity test*

257 During SS, RER ( $P<0.001$ ) and CHO oxidation rate ( $P<0.001$ ) decreased while fat oxidation  
258 increased ( $P<0.001$ ). Average CHO oxidation was higher throughout SS in TRAIN HIGH  
259 than both PERCEPTION ( $P=0.019$ ) and TRAIN LOW ( $P=0.012$ ) while fat oxidation was  
260 lower ( $P=0.016$  and  $0.023$  respectively). Blood glucose was higher throughout SS and HIT  
261 in TRAIN HIGH than in PERCEPTION ( $P=0.002$ ) and TRAIN LOW ( $P=0.021$ ) and also  
262 decreased during exercise ( $P<0.001$ ). Blood lactate rose throughout SS and was significantly  
263 increased in TRAIN HIGH compared with both PERCEPTION ( $P=0.016$ ) and TRAIN LOW  
264 ( $P=0.023$ ) after HIT (see Figure 2).

265

### 266 **Exercise capacity during the HIT test**

267 **High-intensity intermittent** exercise capacity was different between conditions ( $P < 0.001$ ),  
268 whereby TRAIN HIGH ( $22 \pm 9$  min;  $P = 0.005$ : 95% CI for differences = 3 to 16 min, *almost*  
269 *certainly beneficial*) was greater than both PERCEPTION ( $12 \pm 6$  min) and TRAIN LOW ( $8$   
270  $\pm 8$  min;  $P = 0.001$ : 95% CI for differences = 7 to 20 min, *almost certainly beneficial*).  
271 Exercise capacity was also greater in PERCEPTION compared with TRAIN LOW ( $P = 0.025$ :  
272 95% CI for differences = 1 to 8 min, *very likely beneficial*: see Figure 3A). Seven subjects  
273 completed more intervals in PERCEPTION than TRAIN LOW, whilst all nine subjects  
274 completed more intervals in the TRAIN HIGH compared with both non-CHO trials (see  
275 Figure 3B). There was no trial order effect ( $P = 0.849$ ).

276

### 277 **Discussion**

278 Confirming our hypotheses, we provide novel data by demonstrating that perception of CHO  
279 availability augments **high-intensity intermittent** exercise capacity under sleep-low, train-low  
280 conditions though perception does not near restore exercise capacity to that of CHO  
281 consumption. We therefore consider our data to have methodological implications for future  
282 sleep-low train-low research designs by clearly highlighting the requirement for placebo-  
283 controlled trials. Furthermore, when considering that perception of CHO availability can  
284 improve exercise capacity, our data may also have practical applications for those athletes  
285 who deliberately practice CHO periodization strategies in an attempt to strategically enhance  
286 oxidative adaptations of skeletal muscle.

287 To achieve our sleep low, train low model of CHO restriction, we employed a similar  
288 glycogen depletion and re-synthesis protocol to that recently studied in our laboratory  
289 (Harris et al., 2019). Whilst we acknowledge that we did not directly assess muscle  
290 glycogen, evaluations of **substrate utilisation** during the SS exercise protocol **are consistent**

291 **with** differences in CHO availability between the TRAIN HIGH trial and the non-CHO trials.  
292 On the basis of the fitness levels of the present subjects (i.e.  $VO_{2peak}$ ,  $55.3 \pm 8.3$  ml.kg<sup>-1</sup>.min<sup>-1</sup>)  
293 and absolute CHO intake (i.e. 6 g.kg<sup>-1</sup>), we estimate from our previous data (Hearris et al.,  
294 2019) and a recent meta-analysis (Areta & Hopkins, 2018) that muscle glycogen  
295 concentration in TRAIN HIGH was in the region of 300-350 mmol.kg<sup>-1</sup> dw, as opposed to  
296 100-150 mmol.kg<sup>-1</sup> dw in the PERCEPTION and TRAIN LOW trials.

297 Consistent with the well-documented effect of muscle glycogen availability on  
298 exercise capacity (Bergstrom et al., 1967; Hawley et al., 1997; Impey et al., 2016; Hearris et  
299 al., 2019), it is unsurprising that all nine subjects were able to exercise for significantly longer  
300 during the TRAIN HIGH trial compared with the non-CHO trials. The magnitude of  
301 improvement observed here (i.e. ~15 minutes) agrees favorably with our recent data (Hearris  
302 et al., 2019) where we observed that small differences in pre-exercise muscle glycogen  
303 concentration (~100 mmol.kg<sup>-1</sup> dw) improves **high-intensity intermittent** exercise capacity at  
304 80% PPO between ~20% and 50% (8–18 min). In our previous study, however, we  
305 acknowledged that lack of blinding between trials may have influenced subjects' motivation  
306 and perceived ability to complete high-intensity workloads (Hearris et al., 2019). To  
307 overcome the issue of subjects being visually aware of the quantity of CHO rich foods  
308 consumed (Mears et al., 2018), we deliberately chose to blind CHO availability in the present  
309 study by using taste matched beverages delivered in opaque bottles.

310 When comparing subjects' exercise capacity between the TRAIN LOW and water  
311 only FAM trial, it is noteworthy that no significant differences in exercise capacity were  
312 observed. Such data highlight that when subjects were aware that no prior CHO had been  
313 consumed (despite differences in taste between the TRAIN LOW and FAM trials), exercise  
314 capacity was not affected. However, when subjects perceived they had consumed CHO  
315 before sleeping in the PERCEPTION trial, 7 of the 9 subjects performed significantly more

316 work compared with the known TRAIN LOW trial, despite reporting no significant  
317 differences in their motivation to exercise. A placebo effect of CHO availability has been  
318 documented previously (in conditions of normal pre-exercise muscle glycogen concentration)  
319 where CHO has been fed before (Mears et al., 2018) and during (Clark et al., 2000) cycling  
320 time trials equating to durations of approximately 20 and 60 minutes, respectively. In  
321 contrast, no placebo effect of CHO feeding is evident when exercise duration extends beyond  
322 3 hours, likely due to near glycogen depletion and that the metabolic requirement for CHO  
323 dominates over central drive (Hulston & Jeukendrup, 2009). Nonetheless, the present data  
324 demonstrate that a placebo effect of prior CHO ingestion may also manifest in those  
325 conditions where short term-high intensity intermittent exercise is commenced with  
326 considerably reduced pre-exercise muscle glycogen concentration.

327         Whilst we acknowledge that the magnitude of effect with perception was less than  
328 that of actual CHO consumption (~5 versus 15 minutes at 80% PPO), the present data are of  
329 practical relevance for reasons related to both research design and practical application with  
330 athletic populations. Indeed, when considering that previous studies reporting decrements in  
331 power output or exercise capacity during acute train-low training sessions (using the twice  
332 per day or sleep low models) have not blinded subjects to the “low CHO availability”  
333 condition (Hansen et al., 2005; Yeo et al., 2008, 2010; Hulston et al., 2010; Hearn et al.,  
334 2019), it is possible that such impairments in performance may also be due, in part, to  
335 psychological reasons as opposed to physiological factors per se. Similarly, given that  
336 Marquet et al. (2016b) observed that just one week of a sleep-low training intervention  
337 (incorporating only 3 train-low sessions) improved 20 km cycling time trial performance by  
338 3.2%, it is possible that such improvements were simply due to subjects beliefs that the sleep  
339 low protocol would lead to superior improvements in performance, as opposed to  
340 physiological or metabolic adaptations. **In relation to practical application, the placebo**

341 effect of prior CHO intake may also extend the effects of caffeine (Lane et al., 2013) and  
342 CHO mouth rinse (Kasper et al., 2016) as potential tools for which to increase exercise  
343 capacity for those athletes who deliberately practice CHO restriction in an attempt to amplify  
344 training adaptations (Impey et al., 2018).

345 In summary, we provide novel data by demonstrating that perception of CHO  
346 availability augments **high-intensity intermittent** exercise capacity under sleep-low, train-low  
347 conditions though perception does not restore exercise capacity to that of CHO consumption.  
348 Such data have implications for future sleep-low train-low research designs by clearly  
349 highlighting the requirement for placebo-controlled trials. In addition, our data may also have  
350 practical applications for those athletes who deliberately incorporate periods of CHO  
351 restriction into their training programmes in an attempt to strategically enhance mitochondrial  
352 related adaptations of skeletal muscle.

### 353 **Acknowledgement, Authorships, Declarations**

354  
355 The study was designed by JPM, SPW, CS and AP. Data were collected and analysed by  
356 SPW, CS, AP. Data interpretation and manuscript preparation were undertaken by JM, SPW,  
357 CS and AP. All authors approved the final version of the paper. JPM is a consultant for  
358 Science in Sport (SiS). His previous research on glycogen metabolism and exercise has been  
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360

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464 **Figure 1** – Overview of the experimental design.

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466 **Figure 2** – (A) RER, (B) CHO oxidation, (C) lipid oxidation, (D) blood glucose and (E)  
467 blood lactate concentration during the **SS exercise protocol (as completed on the morning of**  
468 **Day 2)**. \*denotes significant difference between TRAIN HIGH and PERCEPTION and  
469 TRAIN LOW trials,  $P < 0.05$ . a denotes significant difference from 10, b denotes significant  
470 difference from 20, c denotes significant difference from 0, d denotes significant difference  
471 from 15 and 30, all  $P < 0.05$ . **Exh, exhaustion.**

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473 **Figure 3** – (A) Exercise capacity (means  $\pm$  SD) and (B) individual subject's exercise capacity  
474 during the TRAIN LOW, PERCEPTION and TRAIN HIGH trials. \*denotes significant  
475 difference from TRAIN LOW, # denotes significant difference from PERCEPTION, both  
476  $P < 0.05$ .

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479 **Table 1** – Heart rate,  $VO_2$  (as % of  $VO_{2peak}$ ) and RPE during the **SS exercise protocol (as**  
 480 **completed on the morning of Day 2) in the** TRAIN LOW, PERCEPTION and TRAIN HIGH  
 481 trials.  
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	<u>Time (min)</u>		
	<b>10</b>	<b>20</b>	<b>30</b>
<b><i>HR (b.min<sup>-1</sup>)</i></b>			
TRAIN LOW	145 ± 16	147 ± 17	150 ± 19 <sup>ab</sup>
PERCEPTION	146 ± 11	149 ± 11	151 ± 14 <sup>ab</sup>
TRAIN HIGH	142 ± 14	143 ± 14	146 ± 15 <sup>ab</sup>
<b><i>% <math>VO_{2peak}</math></i></b>			
TRAIN LOW	61 ± 9	63 ± 7	61 ± 6
PERCEPTION	63 ± 8	64 ± 7	62 ± 6
TRAIN HIGH	64 ± 9	61 ± 9	63 ± 6
<b><i>RPE (AU)</i></b>			
TRAIN LOW	12 ± 2	14 ± 2	16 ± 3 <sup>ab</sup>
PERCEPTION	12 ± 2	13 ± 3	15 ± 3 <sup>ab</sup>
TRAIN HIGH	12 ± 2	14 ± 2	15 ± 3 <sup>ab</sup>

484 a denotes significant difference from 10, b denotes significant difference from 20, both  
 485  $P < 0.05$ .  
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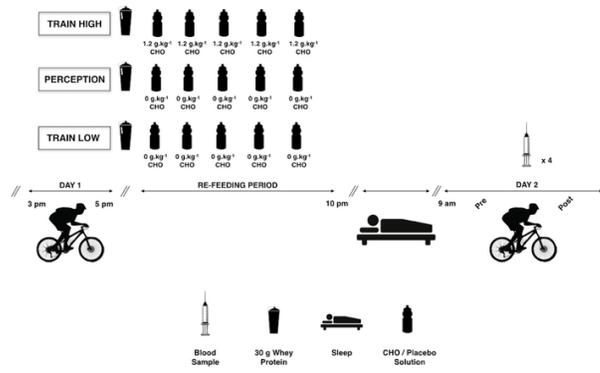


Figure 1 – Overview of the experimental design.

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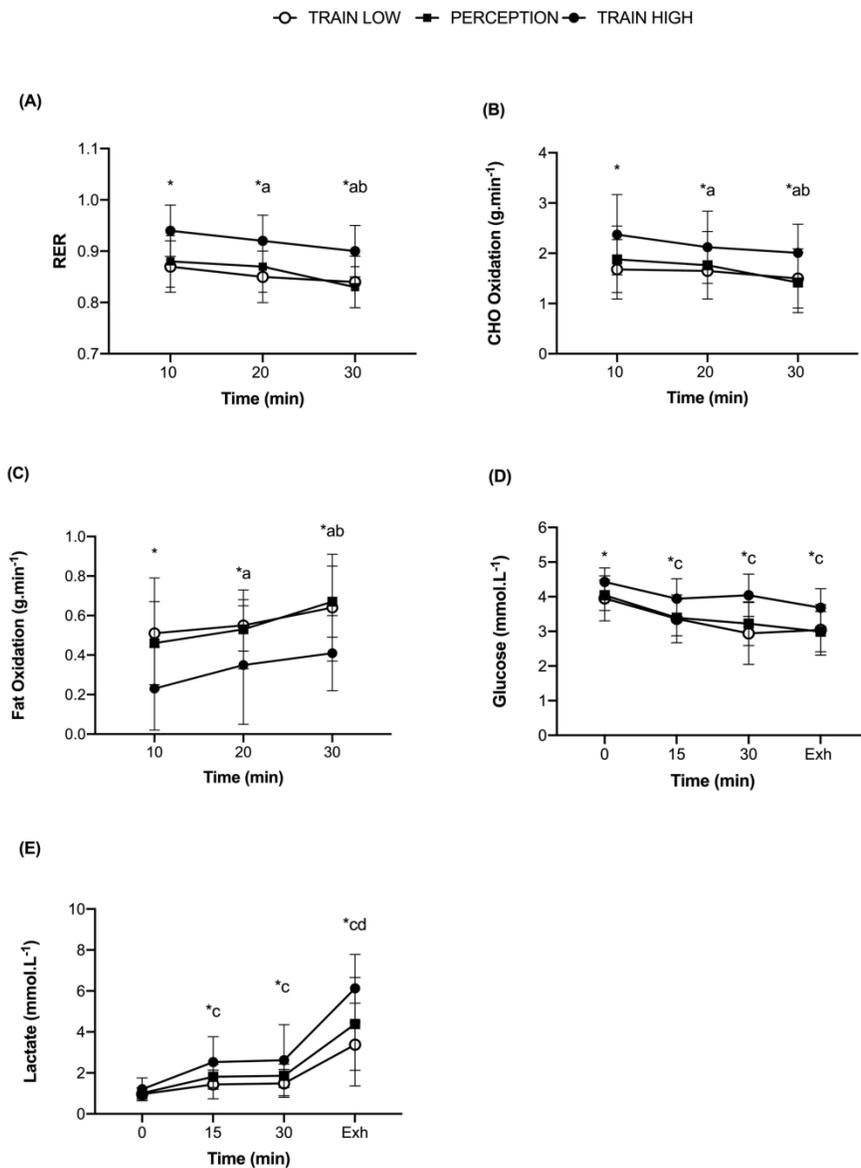


Figure 2 – (A) RER, (B) CHO oxidation, (C) lipid oxidation, (D) blood glucose and (E) blood lactate concentration during the SS exercise protocol (as completed on the morning of Day 2). \*denotes significant difference between TRAIN HIGH and PERCEPTION and TRAIN LOW trials,  $P < 0.05$ . a denotes significant difference from 10, b denotes significant difference from 20, c denotes significant difference from 0, d denotes significant difference from 15 and 30, all  $P < 0.05$ . Exh, exhaustion.

167x215mm (300 x 300 DPI)

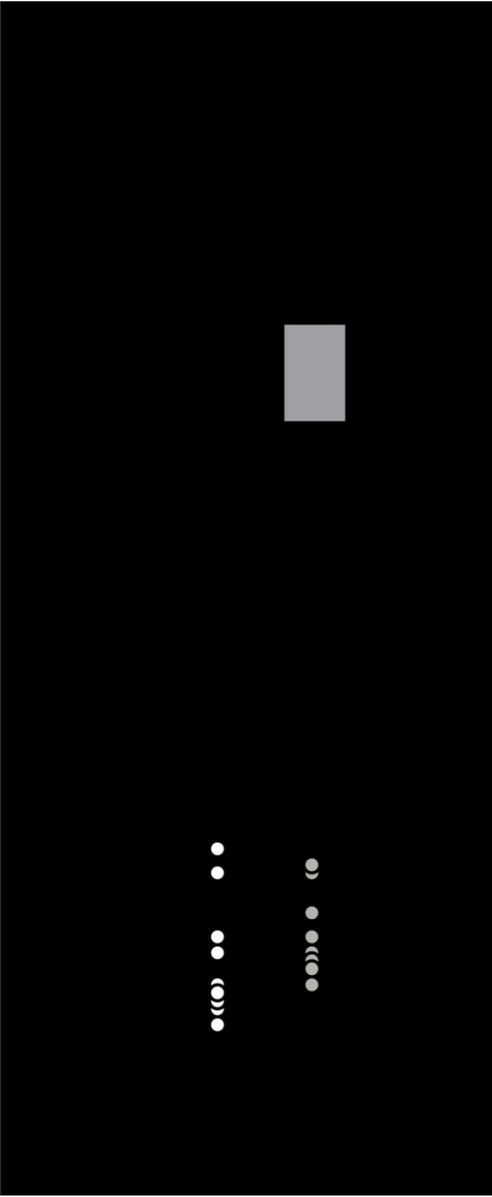


Figure 3 – (A) Exercise capacity (means  $\pm$  SD) and (B) individual subject’s exercise capacity during the TRAIN LOW, PERCEPTION and TRAIN HIGH trials. \*denotes significant difference from TRAIN LOW, # denotes significant difference from PERCEPTION, both  $P < 0.05$ .

80x194mm (300 x 300 DPI)