

1 **Combined prior exercise and fast-start**
2 **improves VO₂ kinetics and cycling performance**

3
4 Original Investigation

5
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28 **Running Title: Pacing, priming, \dot{V}_{O_2} kinetics, performance**

29 **Abstract word count: 243 words**

30 **Text-only word count: 3842 words**

31 **Number of Figures and Tables: 4 Figures and 2 Tables**

32 **ABSTRACT**

33

34 **Purpose:** To investigate whether oxygen uptake (\dot{V}_{O_2}) kinetics and simulated 4-km cycling
35 performance are synergistically improved by prior ‘priming’ exercise and an all-out starting
36 strategy. **Methods:** Nine males completed four target work trials (114 ± 17 kJ) to assess \dot{V}_{O_2}
37 kinetics and cycling performance in a repeated-measures, cross-over experimental design.
38 Trials were initiated with either a 12-s all-out start or a self-selected start and preceded by
39 prior severe-intensity ($70\%\Delta$) priming exercise or no priming exercise. **Results:** The \dot{V}_{O_2}
40 MRT was lower (indicative of faster \dot{V}_{O_2} kinetics) in the all-out primed condition (20 ± 6 s)
41 compared to the all-out unprimed (23 ± 6 s), self-paced-unprimed (42 ± 13 s) and self-paced-
42 primed (42 ± 11 s) trials ($P<0.05$), with the \dot{V}_{O_2} MRT also lower in the all-out unprimed
43 compared to self-paced-unprimed and self-paced-primed trials ($P<0.05$). Trial completion
44 time was shorter (performance was enhanced) in the all-out primed trial (402 ± 14 s)
45 compared to the all-out unprimed (408 ± 14 s), self-paced-unprimed (411 ± 16 s) and self-
46 paced-primed (411 ± 19 s) trials ($P<0.05$) with no differences between the latter three trials.
47 **Conclusions:** The findings from this study suggest that combining severe-intensity priming
48 exercise with a short-duration all-out starting strategy can expedite the adjustment of \dot{V}_{O_2} and
49 lower completion time during a cycling performance trial to a greater extent than either
50 intervention administered independently. These results might have implications for
51 optimising performance in short-duration high-intensity competitive events such as a 4-km
52 cycling time trial.

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55 **Key Words:** Pulmonary \dot{V}_{O_2} , warm-up exercise, fast/all-out start, near-infrared
56 spectroscopy, exercise performance

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70 INTRODUCTION

71
72 The transition from rest to exercise mandates an immediate increase in skeletal muscle
73 contractile activity and ATP turnover. In contrast, the rate of pulmonary oxygen uptake (\dot{V}
74 O_2) increases with exponential response kinetics,¹ which closely reflects the kinetics of
75 muscle \dot{V} O_2 ,² following the onset of exercise. Consequently, a compensatory increase in
76 anaerobic energy liberation is obligatory. Increased dependence on ATP supply through
77 anaerobic metabolism accelerates the depletion of the finite energy reserves, phosphocreatine
78 (PCr) and glycogen, and the accumulation of metabolites such as H^+ , inorganic phosphate,
79 adenosine diphosphate and ammonia, factors which contribute to the development of skeletal
80 muscle fatigue.³ At a given rate of skeletal muscle work and ATP turnover, a more rapid
81 adjustment of \dot{V} O_2 following the onset of exercise would be expected to increase the
82 proportional energy yield from oxidative phosphorylation, lower the energy contribution
83 from anaerobic metabolism and blunt the perturbation to muscle metabolic homeostasis.⁴
84 Therefore, increasing the oxidative energy yield in the initial stages of exercise has the
85 potential to increase the mean skeletal muscle power output during a short-duration high-
86 intensity endurance event resulting in a faster race completion time.⁵

87
88 Completing high-intensity exercise prior to (priming exercise), or adopting a fast-start/all-out
89 starting strategy during, high-intensity exercise has been shown to speed \dot{V} O_2 kinetics and
90 improve exercise performance.⁶⁻¹⁹ We have recently shown that, compared to an unprimed,
91 self-paced control trial, an all-out pacing strategy does not improve 1-km cycling
92 performance more than priming alone²⁰ despite the fact that this pacing strategy is considered
93 optimal for this type of event.^{12,19} Hence, for a 1-km cycling time trial, the ergogenic effects
94 of priming and all-out pacing do not appear to be synergistic. However, it has been suggested
95 that 1.5-km cycling time trial performance can be improved with a short-duration (15-s), but
96 not long-duration (90-s), all-out start compared to a self-selected pacing strategy.²¹
97 Therefore, the all-out pacing strategy administered in our previous study (~90-100-s)²⁰ might
98 have been too long to amplify the priming-induced improvement in performance during the
99 simulated 1-km cycling time trial. It has been suggested that completing priming exercise¹⁸
100 and adopting a short-duration all-out start can independently enhance 4-km cycling
101 performance.^{12,19} However, it has yet to be determined whether combining priming exercise
102 with a **short-duration** faster starting strategy has a synergistic effect on **performance during a**
103 **simulated 4-km cycling time trial and whether this effect is linked to improved muscle**
104 **(de)oxygenation responses or \dot{V} O_2 kinetics and performance during a simulated 4-km cycling**
105 **time trial.** This information might help coaches and athletes optimise performance in such
106 events.

107
108 The purpose of this study was to compare the individual and combined effects of priming
109 exercise and a 12-s all-out start on \dot{V} O_2 kinetics and completion time during simulated 4-km
110 cycling time trials. **Near-infrared spectroscopy was utilised to assess muscle (de)oxygenation**
111 **responses²² and provide insight into the mechanism that might underlie changes in \dot{V} O_2**
112 **kinetics between the different pacing-priming permutations investigated in the current study.**
113 We chose severe-intensity priming with 20 minutes of recovery in conjunction with a 12-s
114 all-out start-strategy because each of these has proven effective in similar events. For
115 example, the former improves exercise tolerance during continuous cycling of similar
116 duration to a 4-km trial,⁹ while the latter optimises 4-km cycling performance.¹² We
117 hypothesised that the pacing and priming interventions would both independently speed
118 **muscle (de)oxygenation and \dot{V} O_2 kinetics and improve cycling performance, but that the**

119 effects would be greater with combined pacing and priming than either intervention
120 administered independently.

121

122 **METHODS**

123 *Subjects*

124 Nine competitive male athletes (mean \pm SD: age 21 ± 3 yr, stature 1.80 ± 0.04 m, body mass
125 77 ± 8 kg) volunteered to participate in this study which was approved by the University of
126 Exeter Research Ethics Committee. All subjects were required to give their written informed
127 consent prior to commencement of the study. Subjects were instructed to arrive at the
128 laboratory in a rested and fully hydrated state, at least 3-h postprandial, and to avoid
129 strenuous exercise in the 24-h preceding each testing session.

130

131 *Experimental Overview*

132 The subjects were required to report to the laboratory on eight occasions over a 4-5-week
133 period with the eight visits separated by at least 48-h. Following the completion of
134 preliminary exercise tests (see below), pulmonary $\dot{V}O_2$, blood [lactate], muscle
135 (de)oxygenation and exercise performance were assessed in four experimental conditions
136 (visits 5-8). These conditions consisted of two different pacing strategies (self-paced and all-
137 out) that were completed with and without priming exercise.

138

139 *Incremental Test*

140 On the first laboratory visit, subjects completed a ramp incremental cycling test for
141 determination of the $\dot{V}O_{2peak}$, gas exchange threshold (GET) and the work rates that would
142 require 65% and 70% Δ (GET work rate plus 65 or 70% of the difference between the work
143 rate at the GET and $\dot{V}O_{2peak}$) as described previously.⁹

144

145 *Familiarisation Trials*

146 During the first familiarisation trial (visit 2), subjects were familiarised to the 'standing' start
147 and were required to complete three target work trials. The resistance on the pedals during
148 the trials was set for each individual using the linear mode of the Lode ergometer so that the
149 subject would attain the power output associated with 65% Δ on reaching a cadence of 90 rpm
150 (linear factor = power/preferred cadence²). Subjects were provided with a 5-s countdown
151 prior to the commencement of all cycling trials. The first trial was used to familiarise
152 subjects to the fixed resistance that would be imposed in all subsequent trials, in addition to
153 serving as a warm up. The target accumulation of work for the first trial was 40-kJ and
154 subjects were instructed to complete this trial at a submaximal cadence of 70-90 rpm.
155 Following a 10-min passive recovery period, subjects completed a self-paced 93-kJ trial
156 where they were instructed to complete the trial in the fastest time possible. Following a
157 further 25-30-min passive recovery, subjects completed a 40-kJ trial using an 'all-out' pacing
158 strategy. This pacing strategy consisted of a 12-s all-out start followed by a self-selected
159 pacing strategy until the 40-kJ work target had been achieved. The power output was
160 continuously recorded at 5-Hz during these trials and averaged into 1-s bins for subsequent
161 analysis. In order to estimate the work required for a completion time of 420-s for each
162 individual subject, the mean power output during the 93-kJ self-paced trial was multiplied by
163 420. This individualised work target was set during all subsequent experimental trials in an
164 attempt to yield a completion time reflective of a 4-km track cycling performance for a
165 trained but sub-elite cyclist.²³

166

167 During the second familiarisation trial (visit 3), subjects were familiarised to the priming
168 exercise protocol and completed two additional trials at their individualised work target. The

169 priming exercise protocol comprised 4-min of baseline cycling at 20 W before an abrupt
170 transition to the severe-intensity target work rate (70% Δ). The severe-intensity priming bout
171 was 3-min in duration. Following a 17-min passive recovery, subjects remounted the cycle
172 ergometer and rested for an additional 3-min. Subjects then completed their individualised
173 work target as quickly as possible using a self-paced pacing strategy. Following 25-30-min
174 passive recovery, subjects completed a third performance trial to 40 kJ using the ‘all-out’
175 pacing strategy.

176

177 In the final familiarisation trial (visit 4), subjects completed their individualised work target
178 as quickly as possible using the all-out pacing strategy. Therefore, all subjects completed six
179 repetitions of the performance trial and one repetition of the priming bout prior to the
180 experimental testing.

181

182 *Experimental Trials*

183 In a randomised order, subjects completed a self-paced trial with and without severe-intensity
184 priming exercise and an all-out trial with and without severe-intensity priming exercise over
185 four separate experimental trials. Subjects were instructed to complete each trial as quickly
186 as possible. Each trial was preceded by 3-min of resting baseline on the cycle ergometer.
187 Ten seconds prior to the commencement of each trial, subjects were instructed to adjust the
188 crank angle to their preferred starting position, which was established in the familiarisation
189 trials and replicated in all experimental trials, and to assume a standing position on the cycle
190 ergometer. Subjects were then provided with a 5-s countdown to indicate when the trial
191 would commence. For the initial 12-s of the trial, subjects were required to cycle in the
192 upright position before being instructed to assume a seated position for the remainder of the
193 trial. Subjects were made aware of their work target prior to each trial and the work target
194 and accrued work during the trial was displayed on a computer screen placed directly in front
195 of the subject. Strong verbal encouragement was provided throughout, but subjects were not
196 aware of the elapsed time during the trials. **A power output profile for a representative
197 individual completing the self-paced unprimed control trial is presented in Figure 1.**

198

199 *Measurements*

200 All cycle tests were performed on an electrically-braked cycle ergometer (Lode Excalibur
201 Sport, Groningen, the Netherlands). During all tests, pulmonary gas exchange and ventilation
202 were measured breath-by-breath using an online gas analyzer (Jaeger Oxycon Pro,
203 Hoechberg, Germany). Muscle oxygenation variables (deoxygenated hemoglobin
204 concentration [HHb], oxygenated hemoglobin concentration [O₂Hb] and total hemoglobin
205 concentration [Hb_{tot}]) were measured using near-infrared spectroscopy (model NIRO 200,
206 Hamamatsu Photonics KK, Hiugashi-ku, Japan). A blood sample was collected from a
207 fingertip into a capillary tube 30-s prior to the commencement of the trial and immediately
208 following the trial for blood [lactate] determination (YSI 1500, Yellow Springs Instruments,
209 Yellow Springs, OH, United States), as described previously.⁸

210

211 *Data Analysis Procedures*

212 **The breath-by-breath \dot{V}_{O_2} data from each test were initially examined to exclude errant
213 breaths caused by coughing, swallowing, sighing, etc., and those values lying more than four
214 standard deviations from the local mean were removed. Subsequently, a custom-designed
215 curve-fitting program using non-linear least-squares regression analysis was employed to ‘fit’
216 the data from each test. ~~Prior to analysis, the breath-by-breath \dot{V}_{O_2} data from each test were
217 treated as described previously.~~⁸ Specifically, a single-exponential model without time delay,
218 with the fitting window commencing at $t = 0$ s (equivalent to the mean response time, MRT)**

219 was used to characterise the kinetics of the overall \dot{V}_{O_2} response during the trials as described
220 in the following equation:

$$221 \dot{V}_{O_2}(t) = \dot{V}_{O_2 \text{ baseline}} + A(1 - e^{-(t/MRT)}) \quad (\text{Eqn. 1})$$

222
223 where $\dot{V}_{O_2}(t)$ represents the absolute \dot{V}_{O_2} at a given time t ; $\dot{V}_{O_2 \text{ baseline}}$ represents the mean \dot{V}_{O_2}
224 measured over the final 90 s of baseline; and A and MRT represent the amplitude and MRT ,
225 respectively, describing the overall increase in \dot{V}_{O_2} above baseline. An iterative process was
226 used to minimise the sum of the squared errors between the fitted function and the observed
227 values. We quantified the \dot{V}_{O_2} MRT with the fitting window constrained to both 120 s and
228 end-exercise (see Figure 1 for an example of the model fit for a representative individual).
229 The absolute \dot{V}_{O_2} at, and the total O_2 consumed up to 60 s (± 5 s) and 120 s (± 5 s) and the
230 ~~minimum completion time for each subject across the four experimental trials (T_{\min}) (mean of~~
231 ~~the final 30 s)~~ were also calculated. We also divided the total O_2 consumed up to 60 s and
232 120 s and ~~T_{\min}~~ by the work accumulated over the corresponding time frame to provide an
233 indication of the oxidative energy provision relative to external work production.
234
235

236 To fit the [HHb] data, we used a modified version of Equation 1 with a time constant (τ ; time
237 to achieve 63% of mono-exponential response amplitude) instead of MRT and time-delay
238 (TD) because the [HHb] response does not increase at $t=0$. The fitting window was
239 constrained from the first data point ≥ 1 SD above the baseline mean to the point at which
240 mono-exponentiality became distorted (as determined by visual inspection of residual plots).
241 The [HHb] TD and τ values were summed to provide information on overall [HHb] kinetics.
242 The [HHb], $[O_2Hb]$ and $[Hb_{\text{tot}}]$ values at baseline (average over the 90 s preceding the onset
243 of the trial), 60 s (± 5 s), 120 s (± 5 s), and end-exercise (average over the final 30 s) were
244 also calculated.
245

246 Performance during the fixed-work trial was determined by the time required to complete the
247 designated work target. Peak power output during the trials was taken as the highest 1-s
248 power output during the trial and end-exercise power output was taken as the mean power
249 output over the final 10 s of the trial.
250

251 *Statistical Analysis*

252 A two-way (pacing x priming) repeated-measures ANOVA was employed to determine the
253 effects of priming exercise and pacing strategy on the relevant physiological and performance
254 variables. Where the analysis revealed a significant difference, individual paired t -tests were
255 employed with a Fisher's LSD to determine the origin of such effects. All data are presented
256 as mean \pm SD. Statistical significance was accepted when $P < 0.05$.
257

258 **RESULTS**

259 The work target for the performance trials was 114 ± 17 kJ and the work rate applied during
260 the severe-intensity priming bout was 247 ± 30 W.
261

262 *Cycling Performance*

263 The total work done over the first 120 s was significantly greater in the all-out trials ($P < 0.05$;
264 Figure 2). Trial completion time was significantly shorter in the all-out primed trial ($402 \pm$
265 14 s $P < 0.05$; Figure 2) compared to the self-paced-unprimed control (411 ± 16 s), the self-
266 paced-primed (411 ± 19 s) and the all-out unprimed (408 ± 14 s) trials ($P < 0.05$), with no
267 difference between the latter three trials ($P > 0.05$).
268

269 \dot{V}_{O_2} Kinetics

270 Regardless of whether the fitting window was constrained to 120 s or end exercise, the \dot{V}_{O_2}
271 MRT was significantly shorter in the all-out primed condition compared to all other
272 experimental conditions and in the all-out unprimed condition compared to both self-paced
273 trials ($P<0.05$; Table 1). Similarly, the total O_2 consumed up to 120 s was significantly
274 greater in the all-out primed condition compared to all other experimental conditions and in
275 the all-out unprimed condition compared to both self-paced trials ($P<0.05$; Table 1; Figure 3).
276 When normalized to the total work done up to various time points, the total O_2 consumed was
277 higher in the all-out compared to the self-paced trials ($P<0.05$; Table 1) up to 120 s and
278 tended to be higher in the all-out primed compared to all-out unprimed trial ($P=0.08$) up to 60
279 s. The end-exercise \dot{V}_{O_2} was higher in the all-out primed ($P<0.05$; Table 1) compared to
280 unprimed trials, but not different compared to the self-paced primed trial ($P>0.05$).

281

282 *Near-infrared Spectroscopy*

283 Muscle [HHb] and [Hb_{tot}] were higher at baseline and throughout exercise in the primed trials
284 ($P<0.05$; Table 2). Muscle [HHb] $\tau + TD$ was shorter in the all-out primed trial compared to
285 all other experimental conditions and in the all-out unprimed compared to the self-paced-
286 unprimed control trial ($P<0.05$; Table 2; Figure 4).

287

288 *Blood [lactate]*

289 Baseline blood [lactate] was significantly greater in the self-paced primed (2.6 ± 0.4 mM) and
290 all-out primed (2.7 ± 0.5 mM) trials compared to the self-paced unprimed (1.1 ± 0.3 mM) and
291 all-out unprimed (1.2 ± 0.4 mM) trials ($P<0.001$). End-exercise blood [lactate] was higher in
292 the self-paced-primed trial (10.5 ± 1.9 mM) compared to the self-paced-unprimed control
293 trial (8.8 ± 2.0 mM; $P<0.05$), but not the all-out-unprimed (9.8 ± 2.7 mM) or all-out-primed
294 (8.9 ± 2.8 mM) trials ($P>0.05$). There were no differences in the change in blood [lactate]
295 from the start to the end of exercise between any of the experimental conditions ($P<0.05$).

296

297 DISCUSSION

298

299 The main original finding from this study is that combining severe-intensity priming exercise
300 with a brief (12-s) all-out start improved simulated 4-km cycling time trial performance. The
301 improved exercise performance exhibited when priming exercise and a faster starting strategy
302 were combined was accompanied by faster muscle HHb kinetics, suggestive of a faster rate
303 of muscle O_2 extraction,²² and faster pulmonary \dot{V}_{O_2} kinetics, suggestive of faster muscle \dot{V}_{O_2}
304 kinetics,² following the onset of the performance trial. These findings suggest that combining
305 priming exercise with a faster starting strategy can improve muscle HHb kinetics, \dot{V}_{O_2}
306 kinetics and performance during a simulated 4-km cycling time trial to a greater extent
307 compared to either of these interventions administered independently. These results might
308 have important implications for optimising performance in endurance events such as 4-km
309 track cycling.

310

311 Commencing a cycling trial with a faster starting strategy resulted in faster overall \dot{V}_{O_2}
312 kinetics and increased total O_2 consumption compared to a self-paced trial, consistent with
313 previous reports.^{6-8,10,14,17,21} Conversely, and in contrast to previous findings,^{9,11,13,15,16,18} the
314 priming regime employed in this study did not alter \dot{V}_{O_2} kinetics during a subsequent self-
315 paced trial. However, combining severe-intensity priming with a faster starting strategy
316 resulted in faster overall \dot{V}_{O_2} kinetics and increased total O_2 consumption compared to either
317 intervention administered independently. An additive effect of priming exercise and a faster
318 starting strategy on \dot{V}_{O_2} kinetics has been observed in some,²⁰ but not all,²⁴ previous studies.

319 Taken together, our findings suggest that adopting a short-duration all-out starting strategy
320 can increase \dot{V}_{O_2} over the initial stages of exercise and that \dot{V}_{O_2} is increased further if this is
321 preceded by a bout of severe-intensity priming exercise. Moreover, there was a higher O_2
322 consumed per unit work done over the first 120 s of exercise, suggestive of a greater
323 proportional energy contribution from oxidative metabolism, in the trials completed with a
324 faster starting strategy compared to the trials completed with a self-paced strategy. There
325 was also a trend ($P=0.08$) for a greater O_2 consumed per unit work done over the first 60 s of
326 exercise with the short-duration all-out starting strategy completed with priming exercise
327 compared to the short-duration all-out starting strategy completed without priming exercise.
328 Therefore our results suggest that, while starting exercise with a short-duration all-out pacing
329 strategy can positively impact \dot{V}_{O_2} kinetics, this effect is augmented when preceded by prior
330 severe-intensity exercise.

331
332 At baseline and throughout exercise, muscle $[Hb_{tot}]$ was higher in the trials completed
333 following priming exercise compared to the trials completed without priming exercise.
334 Muscle $[O_2Hb]$ was also higher at baseline in the trials completed following priming exercise.
335 These results are consistent with previous findings of higher muscle $[O_2Hb]$ and $[Hb_{tot}]$ after
336 priming exercise^{9,20} which suggests a priming exercise-induced increase in skeletal muscle
337 perfusion and O_2 delivery.^{25,26} Therefore, the absence of an effect on \dot{V}_{O_2} kinetics in the
338 trials completed after priming exercise in this study cannot be ascribed to a failure to increase
339 muscle O_2 supply. Although muscle $[O_2Hb]$ and $[Hb_{tot}]$ were not impacted by adopting a
340 short-duration all-out start strategy, muscle $[HHb]$ increased more rapidly in the trials with
341 the faster starting strategy compared to the self-paced trials. Since muscle $[HHb]$ kinetics
342 provides a non-invasive proxy for muscle O_2 extraction kinetics,²² and since \dot{V}_{O_2} kinetics was
343 only expedited during the trials initiated with a faster starting strategy, when muscle $[HHb]$
344 kinetics was also speeded, our results suggest that the faster starting strategy used in this
345 study improved \dot{V}_{O_2} kinetics, principally, by increasing muscle O_2 extraction. This
346 interpretation is further supported by our observation that \dot{V}_{O_2} kinetics was speeded in the
347 faster starting trial preceded by priming exercise, compared to the faster starting trial
348 completed without priming exercise, concomitant with faster muscle $[HHb]$ kinetics.
349 Collectively, these findings suggest that combining severe-intensity priming exercise with a
350 short-duration fast-starting strategy can synergistically speed both \dot{V}_{O_2} and $[HHb]$ kinetics.

351
352 The time required to complete the simulated 4-km cycling time trial (~ 410 s) was shorter
353 (i.e., performance was improved) when priming and the all-out start strategy were combined
354 compared to the self-paced unprimed control trial (2.3%), the self-paced primed trial (2.1%)
355 and the short-duration all-out start trial completed without priming exercise (1.6%).
356 Importantly, performance was similar during these latter three trials, which suggests that
357 when applied exclusively, neither severe-intensity priming exercise nor a short-duration all-
358 out starting strategy improves performance compared to the self-paced unprimed control
359 condition. Previous studies have reported that combining priming exercise with a faster
360 starting strategy does not additively improve exercise performance ~~with performancee~~
361 ~~improved following priming exercise with no further improvements when adopting a faster~~
362 ~~starting strategy.~~^{20,24} For example, performance was enhanced after priming exercise
363 independent of the pacing strategy adopted, but performance was not enhanced when
364 adopting an all-out start without prior priming exercise, during a simulated 1-km cycling time
365 trial (~90-100 s completion time) in our previous study.²⁰ Our findings might conflict with
366 those presented in previous studies due to inter-study differences in the priming exercise and
367 pacing strategies administered, and the duration/distance of the exercise performance test.

368

369 The improved performance in the combined priming exercise and faster start trial was
370 accompanied by faster [HHb] and \dot{V}_{O_2} kinetics, and increased total O₂ consumption and O₂
371 consumed per unit work done over the initial stages of exercise compared to the other
372 experimental conditions. Although these physiological responses were improved in the all-
373 out unprimed trial compared to the self-paced unprimed control trial, these responses were
374 improved further and exercise performance was only enhanced compared to the self-paced
375 unprimed control trial when severe-intensity priming exercise and an all-out start were
376 combined. The higher initial power output in the all-out trials would be expected to increase
377 ATP turnover and the associated perturbation to the phosphorylation potential²⁷ providing a
378 greater stimulus for mitochondrial respiration and muscle O₂ extraction.²⁸ These factors are
379 likely to underpin the faster \dot{V}_{O_2} kinetics in the all-out unprimed trial compared to the self-
380 paced unprimed control trial. In addition, combining the all-out start with severe-intensity
381 priming exercise enhanced muscle O₂ availability, as suggested by the higher muscle [Hb_{tot}]
382 in the current study and evidenced by increased muscle oxygenation and blood flow
383 previously reported after priming exercise.^{9,20,25,26} This might have permitted further
384 improvements in muscle [HHb] and \dot{V}_{O_2} kinetics leading to enhanced performance in the all-
385 out primed trial compared to the all-out unprimed trial.

386
387 The observations in the current study are consistent with our recent findings that performance
388 is optimised during a simulated 1-km time trial when \dot{V}_{O_2} kinetics is speeded concomitant
389 with faster muscle [HHb] kinetics, and increased total O₂ consumption and O₂ consumed per
390 unit work done over the initial stages of exercise.²⁰ In that study, these physiological
391 responses were evoked and performance was optimised with severe-intensity priming
392 exercise independent of the pacing strategy adopted. Conversely, these physiological
393 responses were only evoked, and exercise performance was only enhanced, when severe-
394 intensity priming exercise was combined with a short-duration all-out starting strategy during
395 the simulated 4-km cycling time trial employed in the current study. Together, these findings
396 are important as they suggest that the optimal pacing-priming permutation is likely to differ
397 depending on the race distance and might be discriminated using non-invasive procedures
398 (muscle [HHb] kinetics, total O₂ consumption and O₂ consumed per unit work done over the
399 initial stages of exercise) that can be readily assessed in a laboratory or field setting. These
400 observations might have important implications for coaches and athletes aiming to optimise
401 performance in short-duration track cycling events.

402
403 In conclusion, completing severe-intensity priming exercise prior to, or adopting a short-
404 duration faster starting strategy during, a simulated 4-km cycling time trial in the laboratory
405 did not independently improve trial completion time compared to a self-paced unprimed
406 control trial. However, combining severe-intensity priming exercise and a short-duration
407 faster starting strategy improved simulated 4-km cycling time trial performance. Importantly,
408 performance was optimised when muscle [HHb] and pulmonary \dot{V}_{O_2} kinetics were speeded,
409 and total O₂ consumption and O₂ consumed per unit work done over the initial stages of
410 exercise were increased, suggesting that the ergogenic potential of different pacing-priming
411 permutations might be linked to their ability to improve aspects of pulmonary \dot{V}_{O_2} and
412 muscle deoxygenation kinetics. These findings support the use of combined severe-intensity
413 priming exercise and a short-duration all-out strategy to optimise performance during short-
414 duration high-intensity cycling events such as 4-km track cycling races.

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419 **REFERENCES**

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518 **Figure Legends**

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520 Figure 1. Pulmonary oxygen uptake (\dot{V}_{O_2}) (upper panel) and power output (lower panel)
521 profiles for a representative individual completing the self-paced unprimed controlled trial.
522 The \dot{V}_{O_2} and power output data are presented as 5-s averages. The mono-exponential model
523 fit to the \dot{V}_{O_2} data is indicated by the solid back line with the fitting window commencing at 0
524 s and constrained to 120 s. The solid grey line represents the residuals between the fitted and
525 observed \dot{V}_{O_2} data.

526

527 Figure 2. Total work done up to 60 s (panel A), total work done up to 120 s (panel B), mean
528 power output (panel C) and completion time (panel D) during the target-work cycling trials
529 in the self-paced unprimed (SP-UP), self-paced primed (SP-P), all-out unprimed (AO-UP)
530 and all-out primed (AO-P) conditions. Data are presented as group mean responses with \pm
531 SEM error bars. * indicates higher compared to SP-UP and SP-P ($P<0.01$). # indicates
532 different from SP-UP, SP-P and AO-UP ($P<0.01$).

533

534 Figure 3. Pulmonary oxygen uptake (\dot{V}_{O_2}) over the first 120 s of the self-paced unprimed
535 (SP-UP) trial compared to the self-paced primed (SP-P) trial (upper panel), the all-out
536 unprimed (AO-UP) trial (middle panel) and the all-out primed (AO-P) trial (lower panel).
537 Data are presented as group mean responses with SEM error bars every 15 s. The dashed
538 vertical lines represent the start of the cycling performance trials.

539

540 Figure 4. Near-infrared spectroscopy-derived muscle deoxyhemoglobin concentration
541 ([HHb]) responses over the first 60 s of the self-paced unprimed (SP-UP) trial compared to
542 the self-paced primed (SP-P) trial (upper panel), the all-out unprimed (AO-UP) trial (middle
543 panel) and the all-out primed (AO-P) trial (lower panel). Data are presented as group mean
544 responses with SEM error bars every 15 s. The data are normalised to end-exercise and
545 expressed as the change (Δ) from baseline. The dashed vertical lines represent the start of the
546 cycling performance trial.

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