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Journal of Sports Sciences

Head-to-head competition does not affect pacing or performance in 1 km cycling time trials

--Manuscript Draft--

Full Title:	Head-to-head competition does not affect pacing or performance in 1 km cycling time trials
Manuscript Number:	RJSP-2018-1657R2
Article Type:	Original Manuscript
Keywords:	decision-making; pacing strategy; Competition; Motivation; Sport
Abstract:	<p>Previous research has shown enhanced performance and altered pacing behaviour in the presence of a virtual opponent during middle-distance cycling time trials with duration of two minutes and longer. The purpose of this study was to determine whether these effects are also present in cycling time trials of shorter duration. Twelve physically active men completed three 1 km time trials. After a familiarization trial (FAM), participants performed two experimental conditions: one with no opponent (NO) and one with a virtual opponent (OP). Repeated measures ANOVAs were used to assess differences in pacing and performance using power output and duration ($p < 0.05$). No differences in mean finishing times (FAM: 91.5 ± 7.7 s; NO: 91.6 ± 6.4 s; OP: 90.9 ± 4.9 s; $p = 0.907$) or power output (FAM: 382 ± 111 W; NO: 363 ± 80 W; OP: 367 ± 67; $p = 0.564$) were found between the experimental conditions. In addition, no differences in pacing profiles between experimental conditions were found ($p = 0.199$). Similarly, rate of perceived exertion did not differ between experimental conditions at any moment ($p = 0.831$). In conclusion, unlike events of a more prolonged duration (> 2 minutes), the present study revealed that the presence of an opponent did not affect participants' pacing behaviour in short duration 1 km time trials.</p>
Order of Authors:	<p>Tiffany Wood</p> <p>Connor Thien Long Bui</p> <p>Connor Lubbock</p> <p>Jason Wilson</p> <p>Scott Jeffrey</p> <p>Mitchell Lawrence</p> <p>Colleen Leung</p> <p>Darshit Mashar</p> <p>Nicholas Sims</p> <p>Marco J. Konings</p> <p>Florentina Johanna Hettinga, PhD</p>
Response to Reviewers:	<p>Page 1, Line 5: "with a duration of"</p> <p>Done</p> <p>Page 1, Line 15: Include space "p = 0.199"</p> <p>Done</p> <p>Page 6, Line 144: You state in your reply that all participants started each time trial in the same gear (52/19). I think this information is important and should be added to the manuscript.</p> <p>Done</p> <p>Page 10, Line 255: Replace "found" with "find".</p>

Done

Page 10, Line 264-266: Check grammar.

Done

Figure 1. Mean ($\pm$ SD) power output per 250 m segment per experimental condition.

Figure 2. Mean ($\pm$ SD) RPE scores per experimental condition after 500 m into the time trial and directly after finishing the time trial.

1 **Head-to-head competition does not affect pacing or performance in 1**

2 **km cycling time trials**

3

4 Previous research has shown enhanced performance and altered pacing behaviour in
 5 the presence of a virtual opponent during middle-distance cycling time trials with a
 6 duration of two minutes and longer. The purpose of this study was to determine
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 16 found ($p = 0.199$). Similarly, rate of perceived exertion did not differ between
 17 experimental conditions at any moment ($p = 0.831$). In conclusion, unlike events of a
 18 more prolonged duration (> 2 minutes), the present study revealed that the presence
 19 of an opponent did not affect participants' pacing behaviour in short duration 1 km
 20 time trials.

21 Key words: decision-making; pacing strategy; competition; motivation; sport

22

23 **Introduction**

24 Pacing strategy is a key factor that affects the optimal performance of athletes (Abbiss &
25 Laursen, 2008; Edwards & Polman, 2013; Foster, Hoyos, Earnest, & Lucía, 2005). When
26 employing a sub-optimal pacing strategy, athletes may expend a considerable amount of
27 energy too fast, burning out before the finish and risking injury. Conversely, they may finish
28 the event with reserves still left, but with a lower finishing position than they had the potential
29 to achieve (Abbiss & Laursen, 2008; Foster, Hoyos, Earnest, & Lucía, 2005; Thiel, Foster,
30 Banzer, & De Koning, 2012). A better understanding of factors that influence the pacing
31 decision-making process could help develop more effective pacing strategies to use for athletes
32 and coaches in training and competition, and lead to more effective training protocols and
33 subsequent competitive success (Edwards & Polman, 2013; Smits, Pepping, & Hettinga,
34 2014).

35 Pacing can be defined as a decision-making process about the goal-directed regulation
36 of exercise intensity over an exercise bout in which athletes decide how and when to invest
37 their energy (Edwards & Polman, 2013; Renfree, Martin, Micklewright, & St Clair Gibson,
38 2014; Smits et al., 2014). Until recently, research has focused mostly on internal factors that
39 affect pacing decisions, such as physiology and biomechanics in time trials (Smits et al., 2014).
40 Most sports, however, involve head-to-head competition in which pacing strategies are likely
41 influenced by external factors as well (Hettinga, Konings, & Pepping, 2017; Konings &
42 Hettinga, 2018; Smits et al., 2014). In this respect, the importance of athlete-environment
43 interactions in the context of pacing, such as the interaction between competitors, have been
44 recently emphasized (Hettinga et al., 2017; Konings & Hettinga, 2018; McCormick, Meijen,
45 & Marcora, 2015; Smits et al., 2014; Venhorst, Micklewright, & Noakes, 2017).

46 The controlled situation of a laboratory cycling time trial experiment has proven to
47 be an effective method to explore the environmental influence of a competitor on pacing
48 behaviour and performance over a range of time trial distances (Corbett, Barwood,
49 Ouzounoglou, Thelwell, & Dicks, 2012; Corbett et al., 2018; Konings, Parkinson, Zijdevind,
50 & Hettinga, 2017; Konings, Schoenmakers, Walker, & Hettinga, 2016; Tomazini et al., 2015;

Williams, Jones, Sparks, Marchant, et al., 2015; Williams, Jones, Sparks, Midgley, et al., 2015). The presence of a virtual competitor has been shown to improve performance in 2 km (Corbett et al., 2012), 4 km (Konings et al., 2017; Konings et al., 2016), 16.1 km (Williams, Jones, Sparks, Marchant, et al., 2015; Williams, Jones, Sparks, Midgley, et al., 2015), and 20 km cycling time trials (Corbett et al., 2018), as well as in 5 km running time trials (Tomazini et al., 2015). This performance improvement when racing a competitor has been related to a decreased internal focus of attention (Williams, Jones, Sparks, Marchant, et al., 2015), higher anaerobic contribution (Corbett et al., 2012), improved heat tolerance (Corbett et al., 2018), and the ability to handle higher muscle fatigue without changing perceived exertion (Konings et al., 2017). In addition, the initial behaviour of a virtual opponent has been revealed to alter the initial pacing decisions of cyclists, whereas a faster starting opponent evoked a faster initial pace compared with a slower starting opponent (Konings et al., 2016).

Although the improvement in time trial performance in the presence of a virtual opponent is a consistent finding, all previous studies have examined the impact of a competitor in time trials with a duration of two minutes or longer. This is of importance, as modelling studies clearly show that optimal pacing strategies in short duration events differ compared with events of more prolonged duration (De Koning, Bobbert, & Foster, 1999; De Koning et al., 2011; Foster et al., 2003; Foster, Hoyos, Earnest, & Lucía, 2005; Hettinga, De Koning, Hulleman, & Foster, 2012). In short distance events (< 2 minutes), creatine phosphate depletion is argued to be the main limiting factor, while in longer events (> 2 minutes) rate of substrate depletion, oxygen consumption, heat accumulation and/or accumulation of fatigue-related metabolites (i.e. inorganic phosphate, potassium and hydrogen ions) are argued to be the main limiting factors (Abbiss & Laursen, 2008; Foster, Hoyos, Earnest, & Lucia, 2005; Tucker, 2009). Consequently, it makes sense that different pacing strategies would fit different distances. Pacing in long distance events is characterized by a high power output in the beginning and the end of a race, with a constant power output in between (Foster et al., 2004, 2003). In contrast, to achieve optimal performance in short distance events it has been advised to adopt a fast starting strategy, with a progressive decrease in power output (De Koning et al.,

1999; De Koning, De Groot, & Van Ingen Schenau, 1992; Foster et al., 2004). In this respect, pacing strategies in 250 m, 500 m, and 1 km cycling trials have shown to be different, and even in a 250 m trial peak power is still lower than the potential maximal power output, highlighting the importance of pacing in short time trial events (de Jong et al., 2015). Where these distance-related differences in optimal pacing have been established, it is yet unknown if the presence of competitors impacts differently on pacing and performance in the shorter competitive time trials compared with the more well-researched middle-distance time trials.

Despite the consistent finding of an improvement in time trial performance in the presence of a virtual opponent, it is yet unclear how head-to-head competition affects pacing behaviour and performance on shorter time trials of less than 2 minutes. The aim of this study was therefore to determine if the presence of an opponent changes the pacing strategies of exercisers in 1 km cycling trials compared to when racing alone. Based on previous research in time trials of more prolonged duration, we expect that the presence of an opponent will lead to a more aggressive starting strategy compared with an individual time trial, and to an improvement in performance.

Materials and methods

Participants

Fourteen male participants (age: 24.1 ± 7.2 years; body mass: 80.9 ± 8.8 kg; height: 1.84 ± 0.08 m) participated in this study. Participants were moderate to highly-physically active as they engaged in strenuous activity at least twice a week, and had previous experience with pacing their physical activity during cycling. All participants were experienced to cycling at a moderate to high-intensity, although cycling was for most of them not their first sport. Because of concerns in regards to motivation in some of the time trials, two participants have been excluded out of the analysis. Before taking part, all participants provided informed consent and completed a pre-activity readiness questionnaire (PAR-Q (Cardinal, Esters, & Cardinal, 1996)). The study was approved by the University of Essex local ethical committee in accordance with the Declaration of Helsinki.

107

108 *Experimental procedures*

109 Participants visited the laboratory on three different occasions, to complete a 1 km
110 cycling time-trial as fast as possible. The first time trial was a familiarization trial (FAM),
111 which allowed participants to get accustomed to the procedure and to the Velotron cycle
112 ergometer. The following two trials were the ‘no opponent’ (NO), and the ‘virtual opponent’
113 (OP), respectively. Without being aware of this, the virtual opponent was in fact the
114 performance in NO of the participant. Before each trial, participants performed a standardized
115 warm-up which consisted of 5 minutes of cycling at no more than 100 W at a consistent
116 gearing.

117 Participants were requested to refrain from strenuous exercise and alcohol
118 consumption 24 hours before testing, as well as caffeine and food four hours and two hours
119 prior, respectively. Time trials were completed at the same time of day ($\pm$ 3 hours) and all
120 experimental trials on the same day of the week to minimize circadian variation. All trials were
121 conducted in temperatures between 18-21 °C.

122 Time trials were performed on an advanced cycle ergometer (Velotron Dynafit,
123 Racermate, Seattle, USA). This has proven to be a reliable tool in measuring cycling
124 performance (Astorino & Cottrell, 2012). Using the Velotron 3D software, a straight, flat, 1
125 km course was configured and projected onto a screen in front of the participant showing the
126 course, plus feedback regarding selected gear and distance travelled. In all time-trials a virtual
127 avatar of the participant on the course was projected onto the screen. In the opponent condition
128 (OP), a second virtual avatar representing the opponent was projected onto the screen as well.
129 All participants began each time trial at the same gear (52/19) and were allowed to change
130 gears as they saw fit during the trial. Prior to the first TT, participants found a suitable seat and
131 handle bar height that was recorded and set for them during each of their trials. Before each 1
132 km cycling TT, participants were instructed to complete the 1 km distance as fast as they could.
133 In addition, prior to OP participants were also told that the opponent was of similar capabilities
134 to encourage the perception of possible competition. No further verbal instruction or support

135 was given once the trial began. To prevent any pre-meditated influence on preparation or pre-
136 exercise state, the specific instructions and feedback presented for each trial were only
137 revealed immediately before the start of the time trial.

138 Power output, cadence, distance travelled, and gearing were monitored continuously
139 (sample frequency = 4 Hz). Rate of perceived exertion (RPE) was recorded at each 500 m
140 interval. An A0-sized printed RPE scale was hung up for this next to the screen projector,
141 clearly visible for the participants while sitting on the cycle ergometer. Directly after time trial
142 completion participants were asked to give an estimated finishing time of their time trial in
143 seconds.

144

145 *Statistical analyses*

146 Mean power output, cadence, and finishing time were determined to examine
147 performance. Differences in performance between conditions were assessed using a repeated-
148 measures ANOVA. To assess differences in pacing behaviour between the conditions, average
149 power output, cadence, and split times for each 250 m segment were calculated, and
150 differences were tested using a two-way repeated-measures ANOVA (condition x segment).
151 Post-hoc tests with Bonferroni correction were performed when significant results were found.
152 To assess differences in RPE a two-way repeated-measures ANOVA (condition x distance)
153 was used. Finally, accuracy of the estimated finishing times was evaluated per trial by
154 calculating the mean absolute error between the actual finishing time and the estimated
155 finishing time. All analyses were performed using SPSS 19.0, and significance was accepted
156 at $p < 0.05$. Cohen's d effect sizes are determined, where $d = 0.2$ is considered a small effect
157 size, 0.5 represents a medium effect size and 0.8 a large effect size (Cohen, 1988). Data are
158 presented as means $\pm$ SD.

159

160 **Results**

161 Mean power output, finishing times and cadence per experimental condition can be found in
162 Table 1. In addition, the mean estimated finishing times of the participants directly after time

trial completion, and mean absolute error of this estimated finishing times versus actual finishing times are displayed in Table 1. The repeated measures ANOVA revealed no main effects for power output ($F = 0.588$; $p = 0.564$; $d = 0.14$), finishing time ($F = 0.098$; $p = 0.907$, $d = 0.08$), or cadence ($F = 1.973$; $p = 0.183$; $d = 0.14$).

****Table 1 near here****

****Figure 1 near here****

Mean power outputs per kilometre are shown in Figure 1. A main effect for segment ($F = 15.05$; $p < 0.001$; $d = 0.55$), but not for condition ($F = 0.588$; $p = 0.564$; $d = 0.14$) was found. No interaction effect for condition x segment ($F = 1.769$; $p = 0.199$; $d = 0.26$) was revealed, indicating no differences in pacing profile between conditions. Finally, cadence showed a main effect for segment ($F = 46.52$; $p < 0.001$; $d = 0.69$), indicating differences in chosen cadence over the race. Post-hoc analysis revealed a lower cadence between 0-250 m (98 ± 12 rpm; all $p < 0.01$) compared with the other 250 m segments, and a higher cadence between 250-500 m (117 ± 14 rpm, all $p < 0.01$) compared with all other 250 m segments. Cadence did not differ between the 500-750 m (112 ± 14 rpm) and 750-1000 m segments (110 ± 16 rpm; $p = 0.302$; $d = 0.13$). No main effect for condition ($F = 1.973$; $p = 0.183$; $d = 0.14$) and no condition x segment interaction effect ($F = 0.713$; $p = 0.527$; $d = 0.17$) were found.

Mean ($\pm$ SD) reported RPE scores after 500 m and directly after finishing the time trial per experimental condition are shown in Figure 2. A main effect for distance ($F = 92.59$; $p < 0.001$; $d = 1.49$), but not for condition ($F = 0.314$; $p = 0.627$; $d = 0.16$) were found. No interaction effect for condition x distance ($F = 0.186$; $p = 0.831$; $d = 0.17$) was revealed.

****Figure 2 near here****

Discussion

The aim of the present study was to discover whether the influence of an opponent would alter the pacing behaviour and overall performance over a 1 km cycling time trial. It was proposed

191 that the presence of an opponent would invite a change in pacing and evoke an improvement
192 in performance, in line with research in time-trials of more prolonged duration (Hettinga et al.,
193 2017). However, the results revealed that neither overall performance nor pacing behaviour
194 were altered in the presence of an opponent in 1 km cycling time trials. Therefore, our findings
195 suggest that the duration of the time trial may affect the influence of an opponent on pacing
196 behaviour and performance.

197 Previous research has suggested that the presence of an opponent can evoke certain
198 actions that were not perceived as possible when riding alone (Hettinga et al., 2017). The effect
199 of the presence of a virtual opponent on perceived exertion appeared to be a main underlying
200 factor of why athletes were able to establish the performance improvement in the presence of
201 a virtual competitor. That is, previous studies have found that the presence of an opponent
202 could increase anaerobic contribution (Corbett et al., 2012), improve heat tolerance (Corbett
203 et al., 2018), and enhance the ability to handle higher levels of muscle fatigue without changing
204 perceived exertion (Konings et al., 2017). This might be one of the crucial reasons for the lack
205 of a performance effect in this study. The present study revealed that the presence of a virtual
206 opponent did not alter RPE, indicating that perception of exertion during the trial did not
207 deviate regardless of the presence of a virtual opponent.

208 Previous research has mainly focused on time trials of longer duration than the 1 km
209 distance as used in the present study. In this respect, the differences in limiting factors of a 1
210 km time trial versus time trials of more prolonged duration may explain the lack of a
211 performance effect. In time trial events of two minutes duration or longer, the main limiting
212 factors are thought to be metabolite accumulation, substrate depletion and heat accumulation
213 (Foster et al., 1994; Karlsson & Saltin, 1971; Tucker et al., 2006). In contrast, creatine
214 phosphate depletion is thought to be the main limiting factor in events under two minutes
215 (Foster et al., 1994; Karlsson & Saltin, 1971). Whereas the effect on performance of an
216 opponent is related to a discrepancy in perceived and actual thermophysiological state and/or
217 muscle fatigability (Corbett et al., 2018; Konings et al., 2017), it could be argued that
218 competitor presence is less effective in short duration time trials because heat accumulation

219 and metabolite accumulation are less predominant to achieve optimal performance in this type
220 of time trials.

221 The behaviour of an opponent has also been found to invite cyclists to adjust their own
222 pacing behaviour (Konings et al., 2016). That is, a faster starting opponent evoked a faster
223 start compared with a slower starting opponent (Konings et al., 2016). In the present study no
224 difference in pacing were found in the opponent trial compared with the other trials. However
225 this does not imply that the virtual competitor had no effect on the pacing behaviour of the
226 participant. Whereas the virtual opponent was in fact the performance of the participant in NO,
227 it is not possible to distinguish whether the chosen pacing behaviour was (to a certain extent)
228 evoked by the virtual opponent, or if the participant decided to adopt a similar pacing strategy
229 as in NO. In addition, the short-distance nature may give the athlete less time to process and
230 respond to the invitations provided by the environment about whether to speed up, slow down
231 or maintain the current pace.

232 Knowledge of time elapsed and expected time remaining during the exercise have
233 been highlighted as crucial for optimal pacing regulation (Smits et al., 2014; Smits, Polman,
234 Otten, Pepping, & Hettinga, 2016; Tucker, 2009). However, experimental data examining time
235 perception during time trial exercise is rather limited. Only one study showed recently that
236 self-paced exercise at maximal intensity distorts time perception during both short duration
237 and endurance exercise (Edwards & McCormick, 2017). Their results indicated chronological
238 time appeared to be moving slower than expected at high intensity, possibly due to greater
239 sensory awareness of physical discomfort during maximal effort exercise (Edwards &
240 McCormick, 2017). The present study found in relatively short time trials (< 2 minutes) a mean
241 absolute error in estimated finishing time of 22 seconds in OP to 25 seconds in NO. These
242 results support the finding that time perception seems to be distorted during time trials at
243 maximal intensity, whereas experienced exercisers displayed poor performance in consciously
244 providing an accurate estimation of time elapsed. Distortion of time perception has important
245 implications for pacing and competitive performance if misjudgments occur, particularly in
246 endurance events such as time-trials.

247 A possible limitation of this study was that there was only one familiarization session.
248 It is possible that the lack of familiarization could have influenced their pacing strategy,
249 especially because cycling was for most of our participants not their first sport. However,
250 whereas we did not find a significant change in pacing or performance after the familiarization
251 trial, we believe that this effect was modest if present at all. In addition, all of our participants
252 were moderate to highly-physically active as they engaged in strenuous activity at least twice
253 a week, and had previous experience with pacing their physical activity during high-intensity
254 cycling. A second possible limitation of this study is the lack of randomization between NO
255 and OP. This was the case because the opponent in OP was constructed based on the pacing
256 and performance in NO, and OP was thus always conducted last. However also here, as no
257 differences were found between any of the trials, we do not expect that any substantial
258 additional learning of familiarization effects have occurred that may have affected our
259 outcomes. Finally, one may question if the outcomes would be different if the virtual
260 competitor was constructed to be significantly faster than the performance in the NO condition.
261 However, a different level of performance of the competitor has been shown not to affect the
262 magnitude of performance improvement achieved by the participants (Williams, Jones,
263 Sparks, Midgley, et al., 2015). As such, we perceive it to be unlikely that a faster virtual
264 opponent would have made any differences related to performance.

265 In conclusion, the present study has shown that a virtual opponent does not alter 1 km
266 cycling time trial performance or pacing strategy. This suggests that, unlike for events of more
267 prolonged duration, cyclists are not able to establish an improvement in performance in the
268 presence of a virtual avatar. Previous research has suggested that a virtual opponent could be
269 used as a tool for high-intensity training sessions or to optimize performance (Williams et al.,
270 2015). While this application of a virtual opponent may still hold true in training sessions or
271 races of more prolonged duration, its use can be questioned in training sessions or races of less
272 than two minutes based on the outcomes of this study. These findings suggest that the impact
273 of athlete-environment interactions on performance and the decision-making process involved
274 in pacing to a certain extent depends on the distance and duration of an event.

275

276 **Declaration of interest**

277 The authors report no conflict of interest. This research did not receive any specific grant from
278 funding agencies in the public, commercial, or not-for-profit sectors.

279

280 **References**

- 281 Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies
282 during athletic competition. *Sports Medicine*, 38(3), 239–252.
- 283 Astorino, T. A., & Cottrell, T. (2012). Reliability and validity of the velotron racermate cycle
284 ergometer to measure anaerobic power. *International Journal of Sports Physiology*
285 *and Performance*, 33(3), 205–210.
- 286 Cardinal, B. J., Esters, J., & Cardinal, M. K. (1996). Evaluation of the revised physical
287 activity readiness questionnaire in older adults. *Medicine and Science in Sports and*
288 *Exercise*, 28(4), 468–472.
- 289 Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. New York, NY,
290 USA: Routledge Academic.
- 291 Corbett, J., Barwood, M. J., Ouzounoglou, A., Thelwell, R., & Dicks, M. (2012). Influence
292 of competition on performance and pacing during cycling exercise. *Medicine and*
293 *Science in Sports and Exercise*, 44(3), 509–515.
- 294 Corbett, J., White, D. K., Barwood, M. J., Wagstaff, C. R., Tipton, M. J., McMorris, T., &
295 Costello, J. T. (2018). The Effect of Head-to-Head Competition on Behavioural
296 Thermoregulation, Thermophysiological Strain and Performance During Exercise in
297 the Heat. *Sports Medicine*, 48(5), 1269–1279. [https://doi.org/10.1007/s40279-017-](https://doi.org/10.1007/s40279-017-0816-x)
298 0816-x
- 299 de Jong, J., van der Meijden, L., Hamby, S., Suckow, S., Dodge, C., de Koning, J. J., &
300 Foster, C. (2015). Pacing Strategy in Short Cycling Time Trials. *International*
301 *Journal of Sports Physiology and Performance*, 10(8), 1015–1022.
302 <https://doi.org/10.1123/ijsp.2014-009>
- 303 De Koning, J. J., Bobbert, M. F., & Foster, C. (1999). Determination of optimal pacing
304 strategy in track cycling with an energy flow model. *Journal of Science and*
305 *Medicine in Sport*, 2(3), 266–277.
- 306 De Koning, J. J., De Groot, G., & Van Ingen Schenau, G. J. (1992). A power equation for the
307 sprint in speed skating. *Journal of Biomechanics*, 25(6), 573–580.

308 De Koning, J. J., Foster, C., Lucía, A., Bobbert, M. F., Hettinga, F. J., & Porcari, J. P.
309 (2011). Using modeling to understand how athletes in different disciplines solve the
310 same problem: Swimming versus running versus speed skating. *International*
311 *Journal of Sports Physiology and Performance*, 6(2), 276–280.

312 Edwards, A. M., & McCormick, A. (2017). Time perception, pacing and exercise intensity:
313 maximal exercise distorts the perception of time. *Physiology and Behavior*, 180, 98–
314 102. <https://doi.org/10.1016/j.physbeh.2017.08.009>

315 Edwards, A. M., & Polman, R. C. (2013). Pacing and awareness: brain regulation of physical
316 activity. *Sports Medicine*, 43(11), 1057–1064.

317 Foster, C., De Koning, J. J., Hettinga, F. J., Lampen, J., Dodge, C., Bobbert, M. F., &
318 Porcari, J. P. (2004). Effect of competitive distance on energy expenditure during
319 simulated competition. *International Journal of Sports Medicine*, 25, 198–204.

320 Foster, C., De Koning, J. J., Hettinga, F. J., Lampen, J., La Clair, K. L., Dodge, C., ...
321 Porcari, J. P. (2003). Pattern of energy expenditure during simulated competition.
322 *Medicine and Science in Sports and Exercise*, 35(5), 826–831.

323 Foster, C., Hoyos, J., Earnest, C., & Lucia, A. (2005). Regulation of energy expenditure
324 during prolonged athletic competition. *Medicine and Science in Sports and Exercise*,
325 37(4), 670–675.

326 Foster, C., Hoyos, J., Earnest, C. P., & Lucía, A. (2005). Regulation of energy expenditure
327 during prolonged athletic competition. *Medicine and Science in Sports and Exercise*,
328 37(4), 670–675.

329 Foster, C., Schrager, M., Snyder, A. C., & Thompson, N. N. (1994). Pacing strategy and
330 athletic performance. *Sports Medicine*, 17(2), 77–85.

331 Hettinga, F. J., De Koning, J. J., Hulleman, M., & Foster, C. (2012). Relative importance of
332 pacing strategy and mean power output in 1500-m self-paced cycling. *British*
333 *Journal of Sports Medicine*, 46(1), 30–35.

334 Hettinga, F. J., Konings, M. J., & Pepping, G.-J. (2017). The science of racing against
335 opponents: Affordance competition and the regulation of exercise intensity in head-

336 to-head competition. *Frontiers in Physiology*, 8, 118.
 337 <https://doi.org/10.3389/fphys.2017.00118>

338 Karlsson, J., & Saltin, B. (1971). Oxygen Deficit and Muscle Metabolites in Intermittent
 339 Exercise. *Acta Physiologica*, 82(1), 115–122. [https://doi.org/10.1111/j.1748-](https://doi.org/10.1111/j.1748-1716.1971.tb04948.x)
 340 1716.1971.tb04948.x

341 Konings, M., & Hettinga, F. J. (2018). Pacing decision-making in sport and the effects of
 342 interpersonal competition: a critical review. *Sports Medicine*, 48(8), 1829–1843.
 343 <https://doi.org/10.1007/s40279-018-0937-x>

344 Konings, Marco J, Parkinson, J., Zijdewind, I., & Hettinga, F. J. (2017). Racing an opponent
 345 alters pacing, performance and muscle force decline, but not RPE. *International*
 346 *Journal of Sports Physiology and Performance*, Epub ahead of print.
 347 <https://doi.org/10.1123/ijsp.2017-0220>

348 Konings, M.J., Schoenmakers, P. P. J. M., Walker, A. J., & Hettinga, F. J. (2016). The
 349 behavior of an opponent alters pacing decisions in 4-km cycling time trials.
 350 *Physiology and Behavior*, 158. <https://doi.org/10.1016/j.physbeh.2016.02.023>

351 McCormick, A., Meijen, C., & Marcora, S. M. (2015). Psychological Determinants of
 352 Whole-Body Endurance Performance. *Sports Medicine*, 45(7), 997–1015.
 353 <https://doi.org/10.1007/s40279-015-0319-6>

354 Renfree, A., Martin, L., Micklewright, D., & St Clair Gibson, A. (2014). Application of
 355 decision-making theory to the regulation of muscular work rate during self-paced
 356 competitive endurance activity. *Sports Medicine*, 44(2), 147–158.

357 Smits, B. L., Pepping, G.-J., & Hettinga, F. J. (2014). Pacing and decision making in sport
 358 and exercise: the roles of perception and action in the regulation of exercise
 359 intensity. *Sports Medicine*, 44(6), 763–775.

360 Smits, B. L., Polman, R. C., Otten, E., Pepping, G.-J., & Hettinga, F. J. (2016). Cycling in
 361 the Absence of Task-Related Feedback: Effects on Pacing and Performance.
 362 *Frontiers in Physiology*, 7(August). <https://doi.org/10.3389/fphys.2016.00348>

363 Thiel, C., Foster, C., Banzer, W., & De Koning, J. (2012). Pacing in Olympic track races:
 364 competitive tactics versus best performance strategy. *Journal of Sports Sciences*,
 365 30(11), 1107–1115. <https://doi.org/10.1080/02640414.2012.701759>

366 Tomazini, F., Pasqua, L. A., Damasceno, M. V, Silva-Cavalcante, M. D., De Oliveira, F. R.,
 367 Lima-Silva, A. E., & Bertuzzi, R. C. (2015). Head-to-head running race simulation
 368 alters pacing strategy, performance, and mood state. *Physiology and Behavior*, 149,
 369 39–44.

370 Tucker, R. (2009). The anticipatory regulation of performance: the physiological basis for
 371 pacing strategies and the development of a perception-based model for exercise
 372 performance. *British Journal of Sports Medicine*, 43(6), 392–400.

373 Tucker, R., Marle, T., Lambert, E. V, & Noakes, T. D. (2006). The rate of heat storage
 374 mediates an anticipatory reduction in exercise intensity during cycling at a fixed
 375 rating of perceived exertion. *Journal of Physiology*, 574(Pt 3), 905–915.
 376 <https://doi.org/10.1113/jphysiol.2005.101733>

377 Venhorst, A., Micklewright, D., & Noakes, T. D. (2017). Towards a three-dimensional
 378 framework of centrally regulated and goal-directed exercise behaviour: a narrative
 379 review. *British Journal of Sports Medicine*, 1–12. [https://doi.org/10.1136/bjsports-](https://doi.org/10.1136/bjsports-2016-096907)
 380 2016-096907

381 Williams, E. L., Jones, H. S., Sparks, S. A., Marchant, D. C., Midgley, A. W., &
 382 McNaughton, L. R. (2015). Competitor presence reduces internal attentional focus
 383 and improves 16.1km cycling time trial performance. *Journal of Science and*
 384 *Medicine in Sport*, 18(4), 486–491.

385 Williams, E. L., Jones, H. S., Sparks, S. A., Midgley, A. W., Marchant, D. C., Bridge, C. A.,
 386 & McNaughton, L. R. (2015). Altered Psychological Responses to Different
 387 Magnitudes of Deception during Cycling. *Medicine and Science in Sports and*
 388 *Exercise*, 47(11), 2423–2430. <https://doi.org/10.1249/MSS.0000000000000694>

389

390 **Tables**

Table 1. Mean $\pm$ SD (95% confidence intervals) power output, actual and estimated finishing time and cadence per experimental condition. In addition, the mean absolute error of estimated finishing times versus actual finishing times in seconds.

	FAM	NO	OP
<i>Performance</i>			
Power output (W)	382 $\pm$ 111 (301 - 462)	363 $\pm$ 80 (309 - 417)	367 $\pm$ 67 (322 - 411)
Cadence (rpm)	108 $\pm$ 16 (98 - 119)	108 $\pm$ 14 (98 - 118)	111 $\pm$ 13 (101 - 120)
Finishing time (s)	91.5 $\pm$ 7.7 (86.6 – 96.4)	91.6 $\pm$ 6.4 (87.6 – 95.7)	90.9 $\pm$ 4.9 (87.8 – 94.0)
<i>Time perception</i>			
Estimated finishing time (s)	X ¹	108 $\pm$ 34 (87 - 129)	97 $\pm$ 27 (80 - 113)
Mean absolute error estimated finishing time (s)	X ¹	25 $\pm$ 27 (8 - 43)	22 $\pm$ 16 (12 - 32)

¹ estimated finishing time only asked after NO and OP

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392

393 **Figure captions**

394 **Figure 1.** Mean ($\pm$ SD) power output per 250 m segment per experimental condition.

395 **Figure 2.** Mean ($\pm$ SD) RPE scores per experimental condition after 500 m into the time trial
396 and directly after finishing the time trial.

397

Head-to-head competition does not affect pacing or performance in 1 km cycling time trials

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19 **Head-to-head competition does not affect pacing or performance in** 20 **1 km cycling time trials**

21 Previous research has shown enhanced performance and altered pacing behaviour in
22 the presence of a virtual opponent during middle-distance cycling time trials with a
23 duration of two minutes and longer. The purpose of this study was to determine
24 whether these effects are also present in cycling time trials of shorter duration. Twelve
25 physically active men completed three 1 km time trials. After a familiarization trial
26 (FAM), participants performed two experimental conditions: one with no opponent
27 (NO) and one with a virtual opponent (OP). Repeated measures ANOVAs were used
28 to assess differences in pacing and performance using power output and duration
29 ($p < 0.05$). No differences in mean finishing times (FAM: 91.5 ± 7.7 s; NO: 91.6 ± 6.4
30 s; OP: 90.9 ± 4.9 s; $p = 0.907$) or power output (FAM: 382 ± 111 W; NO: 363 ± 80
31 W; OP: 367 ± 67 ; $p = 0.564$) were found between the experimental conditions. In
32 addition, no differences in pacing profiles between experimental conditions were
33 found ($p = 0.199$). Similarly, rate of perceived exertion did not differ between
34 experimental conditions at any moment ($p = 0.831$). In conclusion, unlike events of a
35 more prolonged duration (> 2 minutes), the present study revealed that the presence
36 of an opponent did not affect participants' pacing behaviour in short duration 1 km
37 time trials.

38 Key words: decision-making; pacing strategy; competition; motivation; sport

39

40 Introduction

41 Pacing strategy is a key factor that affects the optimal performance of athletes (Abbiss &
42 Laursen, 2008; Edwards & Polman, 2013; Foster, Hoyos, Earnest, & Lucía, 2005). When
43 employing a sub-optimal pacing strategy, athletes may expend a considerable amount of
44 energy too fast, burning out before the finish and risking injury. Conversely, they may finish
45 the event with reserves still left, but with a lower finishing position than they had the potential
46 to achieve (Abbiss & Laursen, 2008; Foster, Hoyos, Earnest, & Lucía, 2005; Thiel, Foster,
47 Banzer, & De Koning, 2012). A better understanding of factors that influence the pacing
48 decision-making process could help develop more effective pacing strategies to use for athletes
49 and coaches in training and competition, and lead to more effective training protocols and
50 subsequent competitive success (Edwards & Polman, 2013; Smits, Pepping, & Hettinga,
51 2014).

52 Pacing can be defined as a decision-making process about the goal-directed regulation
53 of exercise intensity over an exercise bout in which athletes decide how and when to invest
54 their energy (Edwards & Polman, 2013; Renfree, Martin, Micklewright, & St Clair Gibson,
55 2014; Smits et al., 2014). Until recently, research has focused mostly on internal factors that
56 affect pacing decisions, such as physiology and biomechanics in time trials (Smits et al., 2014).
57 Most sports, however, involve head-to-head competition in which pacing strategies are likely
58 influenced by external factors as well (Hettinga, Konings, & Pepping, 2017; Konings &
59 Hettinga, 2018; Smits et al., 2014). In this respect, the importance of athlete-environment
60 interactions in the context of pacing, such as the interaction between competitors, have been
61 recently emphasized (Hettinga et al., 2017; Konings & Hettinga, 2018; McCormick, Meijen,
62 & Marcora, 2015; Smits et al., 2014; Venhorst, Micklewright, & Noakes, 2017).

63 The controlled situation of a laboratory cycling time trial experiment has proven to
64 be an effective method to explore the environmental influence of a competitor on pacing
65 behaviour and performance over a range of time trial distances (Corbett, Barwood,
66 Ouzounoglou, Thelwell, & Dicks, 2012; Corbett et al., 2018; Konings, Parkinson, Zijdevind,
67 & Hettinga, 2017; Konings, Schoenmakers, Walker, & Hettinga, 2016; Tomazini et al., 2015;

Williams, Jones, Sparks, Marchant, et al., 2015; Williams, Jones, Sparks, Midgley, et al., 2015). The presence of a virtual competitor has been shown to improve performance in 2 km (Corbett et al., 2012), 4 km (Konings et al., 2017; Konings et al., 2016), 16.1 km (Williams, Jones, Sparks, Marchant, et al., 2015; Williams, Jones, Sparks, Midgley, et al., 2015), and 20 km cycling time trials (Corbett et al., 2018), as well as in 5 km running time trials (Tomazini et al., 2015). This performance improvement when racing a competitor has been related to a decreased internal focus of attention (Williams, Jones, Sparks, Marchant, et al., 2015), higher anaerobic contribution (Corbett et al., 2012), improved heat tolerance (Corbett et al., 2018), and the ability to handle higher muscle fatigue without changing perceived exertion (Konings et al., 2017). In addition, the initial behaviour of a virtual opponent has been revealed to alter the initial pacing decisions of cyclists, whereas a faster starting opponent evoked a faster initial pace compared with a slower starting opponent (Konings et al., 2016).

Although the improvement in time trial performance in the presence of a virtual opponent is a consistent finding, all previous studies have examined the impact of a competitor in time trials with a duration of two minutes or longer. This is of importance, as modelling studies clearly show that optimal pacing strategies in short duration events differ compared with events of more prolonged duration (De Koning, Bobbert, & Foster, 1999; De Koning et al., 2011; Foster et al., 2003; Foster, Hoyos, Earnest, & Lucía, 2005; Hettinga, De Koning, Hulleman, & Foster, 2012). In short distance events (< 2 minutes), creatine phosphate depletion is argued to be the main limiting factor, while in longer events (> 2 minutes) rate of substrate depletion, oxygen consumption, heat accumulation and/or accumulation of fatigue-related metabolites (i.e. inorganic phosphate, potassium and hydrogen ions) are argued to be the main limiting factors (Abbiss & Laursen, 2008; Foster, Hoyos, Earnest, & Lucia, 2005; Tucker, 2009). Consequently, it makes sense that different pacing strategies would fit different distances. Pacing in long distance events is characterized by a high power output in the beginning and the end of a race, with a constant power output in between (Foster et al., 2004, 2003). In contrast, to achieve optimal performance in short distance events it has been advised to adopt a fast starting strategy, with a progressive decrease in power output (De Koning et al.,

1999; De Koning, De Groot, & Van Ingen Schenau, 1992; Foster et al., 2004). In this respect, pacing strategies in 250 m, 500 m, and 1 km cycling trials have shown to be different, and even in a 250 m trial peak power is still lower than the potential maximal power output, highlighting the importance of pacing in short time trial events (de Jong et al., 2015). Where these distance-related differences in optimal pacing have been established, it is yet unknown if the presence of competitors impacts differently on pacing and performance in the shorter competitive time trials compared with the more well-researched middle-distance time trials.

Despite the consistent finding of an improvement in time trial performance in the presence of a virtual opponent, it is yet unclear how head-to-head competition affects pacing behaviour and performance on shorter time trials of less than 2 minutes. The aim of this study was therefore to determine if the presence of an opponent changes the pacing strategies of exercisers in 1 km cycling trials compared to when racing alone. Based on previous research in time trials of more prolonged duration, we expect that the presence of an opponent will lead to a more aggressive starting strategy compared with an individual time trial, and to an improvement in performance.

Materials and methods

Participants

Fourteen male participants (age: 24.1 ± 7.2 years; body mass: 80.9 ± 8.8 kg; height: 1.84 ± 0.08 m) participated in this study. Participants were moderate to highly-physically active as they engaged in strenuous activity at least twice a week, and had previous experience with pacing their physical activity during cycling. All participants were experienced to cycling at a moderate to high-intensity, although cycling was for most of them not their first sport. Because of concerns in regards to motivation in some of the time trials, two participants have been excluded out of the analysis. Before taking part, all participants provided informed consent and completed a pre-activity readiness questionnaire (PAR-Q (Cardinal, Esters, & Cardinal, 1996)). The study was approved by the University of Essex local ethical committee in accordance with the Declaration of Helsinki.

124

125 ***Experimental procedures***

126 Participants visited the laboratory on three different occasions, to complete a 1 km
127 cycling time-trial as fast as possible. The first time trial was a familiarization trial (FAM),
128 which allowed participants to get accustomed to the procedure and to the Velotron cycle
129 ergometer. The following two trials were the ‘no opponent’ (NO), and the ‘virtual opponent’
130 (OP), respectively. Without being aware of this, the virtual opponent was in fact the
131 performance in NO of the participant. Before each trial, participants performed a standardized
132 warm-up which consisted of 5 minutes of cycling at no more than 100 W at a consistent
133 gearing.

134 Participants were requested to refrain from strenuous exercise and alcohol
135 consumption 24 hours before testing, as well as caffeine and food four hours and two hours
136 prior, respectively. Time trials were completed at the same time of day ($\pm$ 3 hours) and all
137 experimental trials on the same day of the week to minimize circadian variation. All trials were
138 conducted in temperatures between 18-21 °C.

139 Time trials were performed on an advanced cycle ergometer (Velotron Dynafit,
140 Racermate, Seattle, USA). This has proven to be a reliable tool in measuring cycling
141 performance (Astorino & Cottrell, 2012). Using the Velotron 3D software, a straight, flat, 1
142 km course was configured and projected onto a screen in front of the participant showing the
143 course, plus feedback regarding selected gear and distance travelled. In all time-trials a virtual
144 avatar of the participant on the course was projected onto the screen. In the opponent condition
145 (OP), a second virtual avatar representing the opponent was projected onto the screen as well.
146 All participants began each time trial at the same gear (52/19) and were allowed to change
147 gears as they saw fit during the trial. Prior to the first TT, participants found a suitable seat and
148 handle bar height that was recorded and set for them during each of their trials. Before each 1
149 km cycling TT, participants were instructed to complete the 1 km distance as fast as they could.
150 In addition, prior to OP participants were also told that the opponent was of similar capabilities
151 to encourage the perception of possible competition. No further verbal instruction or support

152 was given once the trial began. To prevent any pre-meditated influence on preparation or pre-
153 exercise state, the specific instructions and feedback presented for each trial were only
154 revealed immediately before the start of the time trial.

155 Power output, cadence, distance travelled, and gearing were monitored continuously
156 (sample frequency = 4 Hz). Rate of perceived exertion (RPE) was recorded at each 500 m
157 interval. An A0-sized printed RPE scale was hung up for this next to the screen projector,
158 clearly visible for the participants while sitting on the cycle ergometer. Directly after time trial
159 completion participants were asked to give an estimated finishing time of their time trial in
160 seconds.

161

162 *Statistical analyses*

163 Mean power output, cadence, and finishing time were determined to examine
164 performance. Differences in performance between conditions were assessed using a repeated-
165 measures ANOVA. To assess differences in pacing behaviour between the conditions, average
166 power output, cadence, and split times for each 250 m segment were calculated, and
167 differences were tested using a two-way repeated-measures ANOVA (condition x segment).
168 Post-hoc tests with Bonferroni correction were performed when significant results were found.
169 To assess differences in RPE a two-way repeated-measures ANOVA (condition x distance)
170 was used. Finally, accuracy of the estimated finishing times was evaluated per trial by
171 calculating the mean absolute error between the actual finishing time and the estimated
172 finishing time. All analyses were performed using SPSS 19.0, and significance was accepted
173 at $p < 0.05$. Cohen's d effect sizes are determined, where $d = 0.2$ is considered a small effect
174 size, 0.5 represents a medium effect size and 0.8 a large effect size (Cohen, 1988). Data are
175 presented as means $\pm$ SD.

176

177 **Results**

178 Mean power output, finishing times and cadence per experimental condition can be found in
179 Table 1. In addition, the mean estimated finishing times of the participants directly after time

trial completion, and mean absolute error of this estimated finishing times versus actual finishing times are displayed in Table 1. The repeated measures ANOVA revealed no main effects for power output ($F = 0.588$; $p = 0.564$; $d = 0.14$), finishing time ($F = 0.098$; $p = 0.907$, $d = 0.08$), or cadence ($F = 1.973$; $p = 0.183$; $d = 0.14$).

****Table 1 near here****

****Figure 1 near here****

Mean power outputs per kilometre are shown in Figure 1. A main effect for segment ($F = 15.05$; $p < 0.001$; $d = 0.55$), but not for condition ($F = 0.588$; $p = 0.564$; $d = 0.14$) was found. No interaction effect for condition x segment ($F = 1.769$; $p = 0.199$; $d = 0.26$) was revealed, indicating no differences in pacing profile between conditions. Finally, cadence showed a main effect for segment ($F = 46.52$; $p < 0.001$; $d = 0.69$), indicating differences in chosen cadence over the race. Post-hoc analysis revealed a lower cadence between 0-250 m (98 ± 12 rpm; all $p < 0.01$) compared with the other 250 m segments, and a higher cadence between 250-500 m (117 ± 14 rpm, all $p < 0.01$) compared with all other 250 m segments. Cadence did not differ between the 500-750 m (112 ± 14 rpm) and 750-1000 m segments (110 ± 16 rpm; $p = 0.302$; $d = 0.13$). No main effect for condition ($F = 1.973$; $p = 0.183$; $d = 0.14$) and no condition x segment interaction effect ($F = 0.713$; $p = 0.527$; $d = 0.17$) were found.

Mean ($\pm$ SD) reported RPE scores after 500 m and directly after finishing the time trial per experimental condition are shown in Figure 2. A main effect for distance ($F = 92.59$; $p < 0.001$; $d = 1.49$), but not for condition ($F = 0.314$; $p = 0.627$; $d = 0.16$) were found. No interaction effect for condition x distance ($F = 0.186$; $p = 0.831$; $d = 0.17$) was revealed.

****Figure 2 near here****

Discussion

The aim of the present study was to discover whether the influence of an opponent would alter the pacing behaviour and overall performance over a 1 km cycling time trial. It was proposed

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208 that the presence of an opponent would invite a change in pacing and evoke an improvement
209 in performance, in line with research in time-trials of more prolonged duration (Hettinga et al.,
210 2017). However, the results revealed that neither overall performance nor pacing behaviour
211 were altered in the presence of an opponent in 1 km cycling time trials. Therefore, our findings
212 suggest that the duration of the time trial may affect the influence of an opponent on pacing
213 behaviour and performance.

214 Previous research has suggested that the presence of an opponent can evoke certain
215 actions that were not perceived as possible when riding alone (Hettinga et al., 2017). The effect
216 of the presence of a virtual opponent on perceived exertion appeared to be a main underlying
217 factor of why athletes were able to establish the performance improvement in the presence of
218 a virtual competitor. That is, previous studies have found that the presence of an opponent
219 could increase anaerobic contribution (Corbett et al., 2012), improve heat tolerance (Corbett
220 et al., 2018), and enhance the ability to handle higher levels of muscle fatigue without changing
221 perceived exertion (Konings et al., 2017). This might be one of the crucial reasons for the lack
222 of a performance effect in this study. The present study revealed that the presence of a virtual
223 opponent did not alter RPE, indicating that perception of exertion during the trial did not
224 deviate regardless of the presence of a virtual opponent.

225 Previous research has mainly focused on time trials of longer duration than the 1 km
226 distance as used in the present study. In this respect, the differences in limiting factors of a 1
227 km time trial versus time trials of more prolonged duration may explain the lack of a
228 performance effect. In time trial events of two minutes duration or longer, the main limiting
229 factors are thought to be metabolite accumulation, substrate depletion and heat accumulation
230 (Foster et al., 1994; Karlsson & Saltin, 1971; Tucker et al., 2006). In contrast, creatine
231 phosphate depletion is thought to be the main limiting factor in events under two minutes
232 (Foster et al., 1994; Karlsson & Saltin, 1971). Whereas the effect on performance of an
233 opponent is related to a discrepancy in perceived and actual thermophysiological state and/or
234 muscle fatigability (Corbett et al., 2018; Konings et al., 2017), it could be argued that
235 competitor presence is less effective in short duration time trials because heat accumulation

236 and metabolite accumulation are less predominant to achieve optimal performance in this type
237 of time trials.

238 The behaviour of an opponent has also been found to invite cyclists to adjust their own
239 pacing behaviour (Konings et al., 2016). That is, a faster starting opponent evoked a faster
240 start compared with a slower starting opponent (Konings et al., 2016). In the present study no
241 difference in pacing were found in the opponent trial compared with the other trials. However
242 this does not imply that the virtual competitor had no effect on the pacing behaviour of the
243 participant. Whereas the virtual opponent was in fact the performance of the participant in NO,
244 it is not possible to distinguish whether the chosen pacing behaviour was (to a certain extent)
245 evoked by the virtual opponent, or if the participant decided to adopt a similar pacing strategy
246 as in NO. In addition, the short-distance nature may give the athlete less time to process and
247 respond to the invitations provided by the environment about whether to speed up, slow down
248 or maintain the current pace.

249 Knowledge of time elapsed and expected time remaining during the exercise have
250 been highlighted as crucial for optimal pacing regulation (Smits et al., 2014; Smits, Polman,
251 Otten, Pepping, & Hettinga, 2016; Tucker, 2009). However, experimental data examining time
252 perception during time trial exercise is rather limited. Only one study showed recently that
253 self-paced exercise at maximal intensity distorts time perception during both short duration
254 and endurance exercise (Edwards & McCormick, 2017). Their results indicated chronological
255 time appeared to be moving slower than expected at high intensity, possibly due to greater
256 sensory awareness of physical discomfort during maximal effort exercise (Edwards &
257 McCormick, 2017). The present study found in relatively short time trials (< 2 minutes) a mean
258 absolute error in estimated finishing time of 22 seconds in OP to 25 seconds in NO. These
259 results support the finding that time perception seems to be distorted during time trials at
260 maximal intensity, whereas experienced exercisers displayed poor performance in consciously
261 providing an accurate estimation of time elapsed. Distortion of time perception has important
262 implications for pacing and competitive performance if misjudgments occur, particularly in
263 endurance events such as time-trials.

264 A possible limitation of this study was that there was only one familiarization session.
 265 It is possible that the lack of familiarization could have influenced their pacing strategy,
 266 especially because cycling was for most of our participants not their first sport. However,
 267 whereas we did not find a significant change in pacing or performance after the familiarization
 268 trial, we believe that this effect was modest if present at all. In addition, all of our participants
 269 were moderate to highly-physically active as they engaged in strenuous activity at least twice
 270 a week, and had previous experience with pacing their physical activity during high-intensity
 271 cycling. A second possible limitation of this study is the lack of randomization between NO
 272 and OP. This was the case because the opponent in OP was constructed based on the pacing
 273 and performance in NO, and OP was thus always conducted last. However also here, as no
 274 differences were found between any of the trials, we do not expect that any substantial
 275 additional learning of familiarization effects have occurred that may have affected our
 276 outcomes. Finally, one may question if the outcomes would be different if the virtual
 277 competitor was constructed to be significantly faster than the performance in the NO condition.
 278 However, a different level of performance of the competitor has been shown not to affect the
 279 magnitude of performance improvement achieved by the participants (Williams, Jones,
 280 Sparks, Midgley, et al., 2015). As such, we perceive it to be unlikely that a faster virtual
 281 opponent would have made any differences related to performance.

282 In conclusion, the present study has shown that a virtual opponent does not alter 1 km
 283 cycling time trial performance or pacing strategy. This suggests that, unlike for events of more
 284 prolonged duration, cyclists are not able to establish an improvement in performance in the
 285 presence of a virtual avatar. Previous research has suggested that a virtual opponent could be
 286 used as a tool for high-intensity training sessions or to optimize performance (Williams et al.,
 287 2015). While this application of a virtual opponent may still hold true in training sessions or
 288 races of more prolonged duration, its use can be questioned in training sessions or races of less
 289 than two minutes based on the outcomes of this study. These findings suggest that the impact
 290 of athlete-environment interactions on performance and the decision-making process involved
 291 in pacing to a certain extent depends on the distance and duration of an event.

292

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295 this study.

296

297 **Declaration of interest**

298 The authors report no conflict of interest. This research did not receive any specific grant from
299 funding agencies in the public, commercial, or not-for-profit sectors.

300

References

- Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Medicine*, 38(3), 239–252.
- Astorino, T. A., & Cottrell, T. (2012). Reliability and validity of the velotron racermate cycle ergometer to measure anaerobic power. *International Journal of Sports Physiology and Performance*, 33(3), 205–210.
- Cardinal, B. J., Esters, J., & Cardinal, M. K. (1996). Evaluation of the revised physical activity readiness questionnaire in older adults. *Medicine and Science in Sports and Exercise*, 28(4), 468–472.
- Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. New York, NY, USA: Routledge Academic.
- Corbett, J., Barwood, M. J., Ouzounoglou, A., Thelwell, R., & Dicks, M. (2012). Influence of competition on performance and pacing during cycling exercise. *Medicine and Science in Sports and Exercise*, 44(3), 509–515.
- Corbett, J., White, D. K., Barwood, M. J., Wagstaff, C. R., Tipton, M. J., McMorris, T., & Costello, J. T. (2018). The Effect of Head-to-Head Competition on Behavioural Thermoregulation, Thermophysiological Strain and Performance During Exercise in the Heat. *Sports Medicine*, 48(5), 1269–1279. <https://doi.org/10.1007/s40279-017-0816-x>
- de Jong, J., van der Meijden, L., Hamby, S., Suckow, S., Dodge, C., de Koning, J. J., & Foster, C. (2015). Pacing Strategy in Short Cycling Time Trials. *International Journal of Sports Physiology and Performance*, 10(8), 1015–1022. <https://doi.org/10.1123/ijsp.2014-009>
- De Koning, J. J., Bobbert, M. F., & Foster, C. (1999). Determination of optimal pacing strategy in track cycling with an energy flow model. *Journal of Science and Medicine in Sport*, 2(3), 266–277.
- De Koning, J. J., De Groot, G., & Van Ingen Schenau, G. J. (1992). A power equation for the sprint in speed skating. *Journal of Biomechanics*, 25(6), 573–580.

- De Koning, J. J., Foster, C., Lucía, A., Bobbert, M. F., Hettinga, F. J., & Porcari, J. P. (2011). Using modeling to understand how athletes in different disciplines solve the same problem: Swimming versus running versus speed skating. *International Journal of Sports Physiology and Performance*, 6(2), 276–280.
- Edwards, A. M., & McCormick, A. (2017). Time perception, pacing and exercise intensity: maximal exercise distorts the perception of time. *Physiology and Behavior*, 180, 98–102. <https://doi.org/10.1016/j.physbeh.2017.08.009>
- Edwards, A. M., & Polman, R. C. (2013). Pacing and awareness: brain regulation of physical activity. *Sports Medicine*, 43(11), 1057–1064.
- Foster, C., De Koning, J. J., Hettinga, F. J., Lampen, J., Dodge, C., Bobbert, M. F., & Porcari, J. P. (2004). Effect of competitive distance on energy expenditure during simulated competition. *International Journal of Sports Medicine*, 25, 198–204.
- Foster, C., De Koning, J. J., Hettinga, F. J., Lampen, J., La Clair, K. L., Dodge, C., ... Porcari, J. P. (2003). Pattern of energy expenditure during simulated competition. *Medicine and Science in Sports and Exercise*, 35(5), 826–831.
- Foster, C., Hoyos, J., Earnest, C., & Lucia, A. (2005). Regulation of energy expenditure during prolonged athletic competition. *Medicine and Science in Sports and Exercise*, 37(4), 670–675.
- Foster, C., Hoyos, J., Earnest, C. P., & Lucía, A. (2005). Regulation of energy expenditure during prolonged athletic competition. *Medicine and Science in Sports and Exercise*, 37(4), 670–675.
- Foster, C., Schrager, M., Snyder, A. C., & Thompson, N. N. (1994). Pacing strategy and athletic performance. *Sports Medicine*, 17(2), 77–85.
- Hettinga, F. J., De Koning, J. J., Hulleman, M., & Foster, C. (2012). Relative importance of pacing strategy and mean power output in 1500-m self-paced cycling. *British Journal of Sports Medicine*, 46(1), 30–35.
- Hettinga, F. J., Konings, M. J., & Pepping, G.-J. (2017). The science of racing against opponents: Affordance competition and the regulation of exercise intensity in head-

357 to-head competition. *Frontiers in Physiology*, 8, 118.
358 <https://doi.org/10.3389/fphys.2017.00118>
359 Karlsson, J., & Saltin, B. (1971). Oxygen Deficit and Muscle Metabolites in Intermittent
360 Exercise. *Acta Physiologica*, 82(1), 115–122. [https://doi.org/10.1111/j.1748-](https://doi.org/10.1111/j.1748-1716.1971.tb04948.x)
361 1716.1971.tb04948.x
362 Konings, M., & Hettinga, F. J. (2018). Pacing decision-making in sport and the effects of
363 interpersonal competition: a critical review. *Sports Medicine*, 48(8), 1829–1843.
364 <https://doi.org/10.1007/s40279-018-0937-x>
365 Konings, Marco J, Parkinson, J., Zijdewind, I., & Hettinga, F. J. (2017). Racing an opponent
366 alters pacing, performance and muscle force decline, but not RPE. *International*
367 *Journal of Sports Physiology and Performance*, Epub ahead of print.
368 <https://doi.org/10.1123/ijsp.2017-0220>
369 Konings, M.J., Schoenmakers, P. P. J. M., Walker, A. J., & Hettinga, F. J. (2016). The
370 behavior of an opponent alters pacing decisions in 4-km cycling time trials.
371 *Physiology and Behavior*, 158. <https://doi.org/10.1016/j.physbeh.2016.02.023>
372 McCormick, A., Meijen, C., & Marcora, S. M. (2015). Psychological Determinants of
373 Whole-Body Endurance Performance. *Sports Medicine*, 45(7), 997–1015.
374 <https://doi.org/10.1007/s40279-015-0319-6>
375 Renfree, A., Martin, L., Micklewright, D., & St Clair Gibson, A. (2014). Application of
376 decision-making theory to the regulation of muscular work rate during self-paced
377 competitive endurance activity. *Sports Medicine*, 44(2), 147–158.
378 Smits, B. L., Pepping, G.-J., & Hettinga, F. J. (2014). Pacing and decision making in sport
379 and exercise: the roles of perception and action in the regulation of exercise
380 intensity. *Sports Medicine*, 44(6), 763–775.
381 Smits, B. L., Polman, R. C., Otten, E., Pepping, G.-J., & Hettinga, F. J. (2016). Cycling in
382 the Absence of Task-Related Feedback: Effects on Pacing and Performance.
383 *Frontiers in Physiology*, 7(August). <https://doi.org/10.3389/fphys.2016.00348>

- Thiel, C., Foster, C., Banzer, W., & De Koning, J. (2012). Pacing in Olympic track races: competitive tactics versus best performance strategy. *Journal of Sports Sciences*, 30(11), 1107–1115. <https://doi.org/10.1080/02640414.2012.701759>
- Tomazini, F., Pasqua, L. A., Damasceno, M. V, Silva-Cavalcante, M. D., De Oliveira, F. R., Lima-Silva, A. E., & Bertuzzi, R. C. (2015). Head-to-head running race simulation alters pacing strategy, performance, and mood state. *Physiology and Behavior*, 149, 39–44.
- Tucker, R. (2009). The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. *British Journal of Sports Medicine*, 43(6), 392–400.
- Tucker, R., Marle, T., Lambert, E. V, & Noakes, T. D. (2006). The rate of heat storage mediates an anticipatory reduction in exercise intensity during cycling at a fixed rating of perceived exertion. *Journal of Physiology*, 574(Pt 3), 905–915. <https://doi.org/10.1113/jphysiol.2005.101733>
- Venhorst, A., Micklewright, D., & Noakes, T. D. (2017). Towards a three-dimensional framework of centrally regulated and goal-directed exercise behaviour: a narrative review. *British Journal of Sports Medicine*, 1–12. <https://doi.org/10.1136/bjsports-2016-096907>
- Williams, E. L., Jones, H. S., Sparks, S. A., Marchant, D. C., Midgley, A. W., & McNaughton, L. R. (2015). Competitor presence reduces internal attentional focus and improves 16.1km cycling time trial performance. *Journal of Science and Medicine in Sport*, 18(4), 486–491.
- Williams, E. L., Jones, H. S., Sparks, S. A., Midgley, A. W., Marchant, D. C., Bridge, C. A., & McNaughton, L. R. (2015). Altered Psychological Responses to Different Magnitudes of Deception during Cycling. *Medicine and Science in Sports and Exercise*, 47(11), 2423–2430. <https://doi.org/10.1249/MSS.0000000000000694>

411 Tables

Table 1. Mean $\pm$ SD (95% confidence intervals) power output, actual and estimated finishing time and cadence per experimental condition. In addition, the mean absolute error of estimated finishing times versus actual finishing times in seconds.

	FAM	NO	OP
<i>Performance</i>			
Power output (W)	382 $\pm$ 111 (301 - 462)	363 $\pm$ 80 (309 - 417)	367 $\pm$ 67 (322 - 411)
Cadence (rpm)	108 $\pm$ 16 (98 - 119)	108 $\pm$ 14 (98 - 118)	111 $\pm$ 13 (101 - 120)
Finishing time (s)	91.5 $\pm$ 7.7 (86.6 – 96.4)	91.6 $\pm$ 6.4 (87.6 – 95.7)	90.9 $\pm$ 4.9 (87.8 – 94.0)
<i>Time perception</i>			
Estimated finishing time (s)	X ¹	108 $\pm$ 34 (87 - 129)	97 $\pm$ 27 (80 - 113)
Mean absolute error estimated finishing time (s)	X ¹	25 $\pm$ 27 (8 - 43)	22 $\pm$ 16 (12 - 32)

¹ estimated finishing time only asked after NO and OP

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414 **Figure captions**

415 **Figure 1.** Mean ($\pm$ SD) power output per 250 m segment per experimental condition.

416 **Figure 2.** Mean ($\pm$ SD) RPE scores per experimental condition after 500 m into the time trial

417 and directly after finishing the time trial.

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