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# Journal of Sports Sciences

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

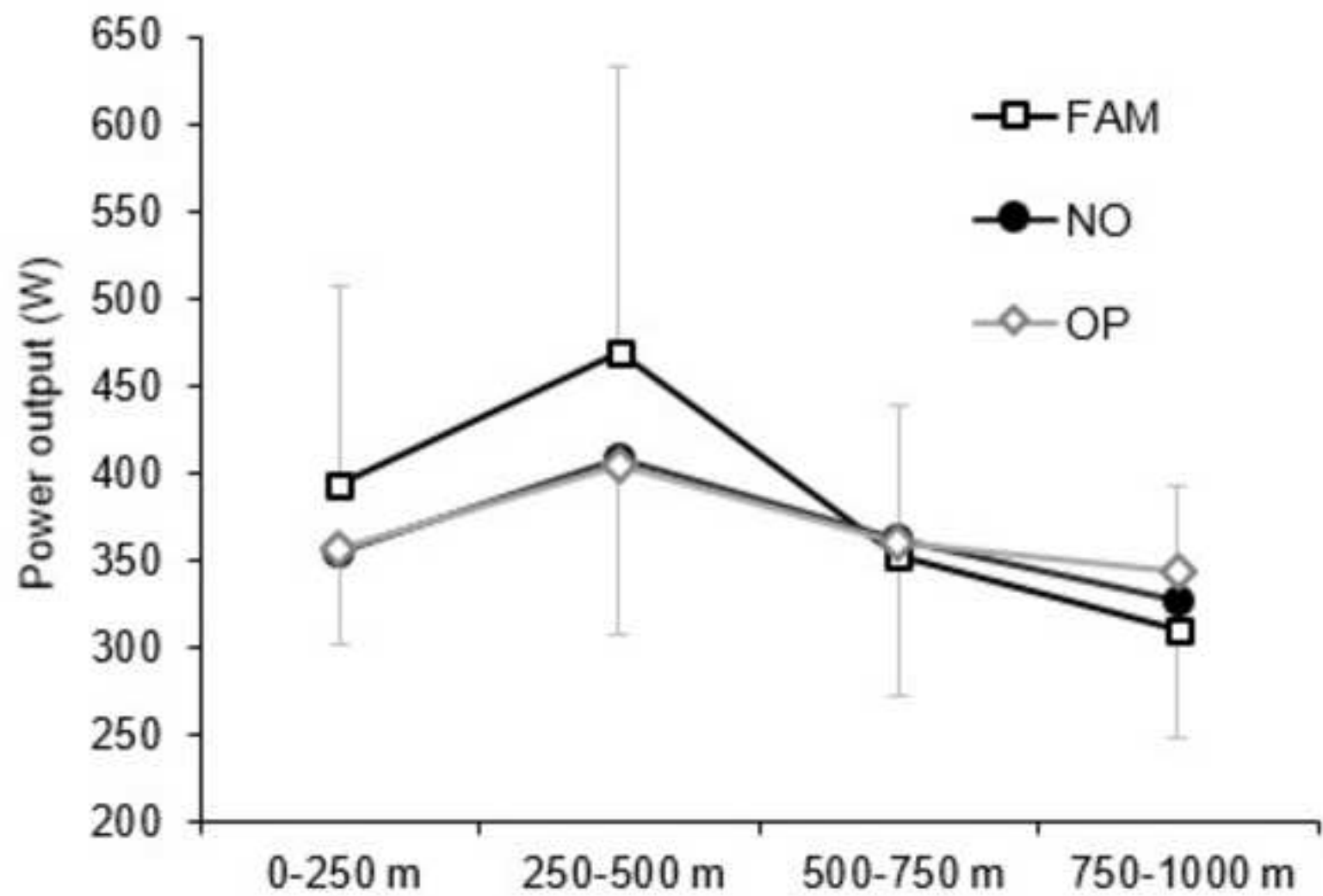
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<b>Full Title:</b>	Head-to-head competition does not affect pacing or performance in 1 km cycling time trials
<b>Manuscript Number:</b>	RJSP-2018-1657R2
<b>Article Type:</b>	Original Manuscript
<b>Keywords:</b>	decision-making; pacing strategy; Competition; Motivation; Sport
<b>Abstract:</b>	<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 (<math>p &lt; 0.05</math>). No differences in mean finishing times (FAM: <math>91.5 \pm 7.7</math> s; NO: <math>91.6 \pm 6.4</math> s; OP: <math>90.9 \pm 4.9</math> s; <math>p = 0.907</math>) or power output (FAM: <math>382 \pm 111</math> W; NO: <math>363 \pm 80</math> W; OP: <math>367 \pm 67</math>; <math>p = 0.564</math>) were found between the experimental conditions. In addition, no differences in pacing profiles between experimental conditions were found (<math>p = 0.199</math>). Similarly, rate of perceived exertion did not differ between experimental conditions at any moment (<math>p = 0.831</math>). In conclusion, unlike events of a more prolonged duration (<math>&gt; 2</math> 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>
<b>Order of Authors:</b>	<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>
<b>Response to Reviewers:</b>	<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>

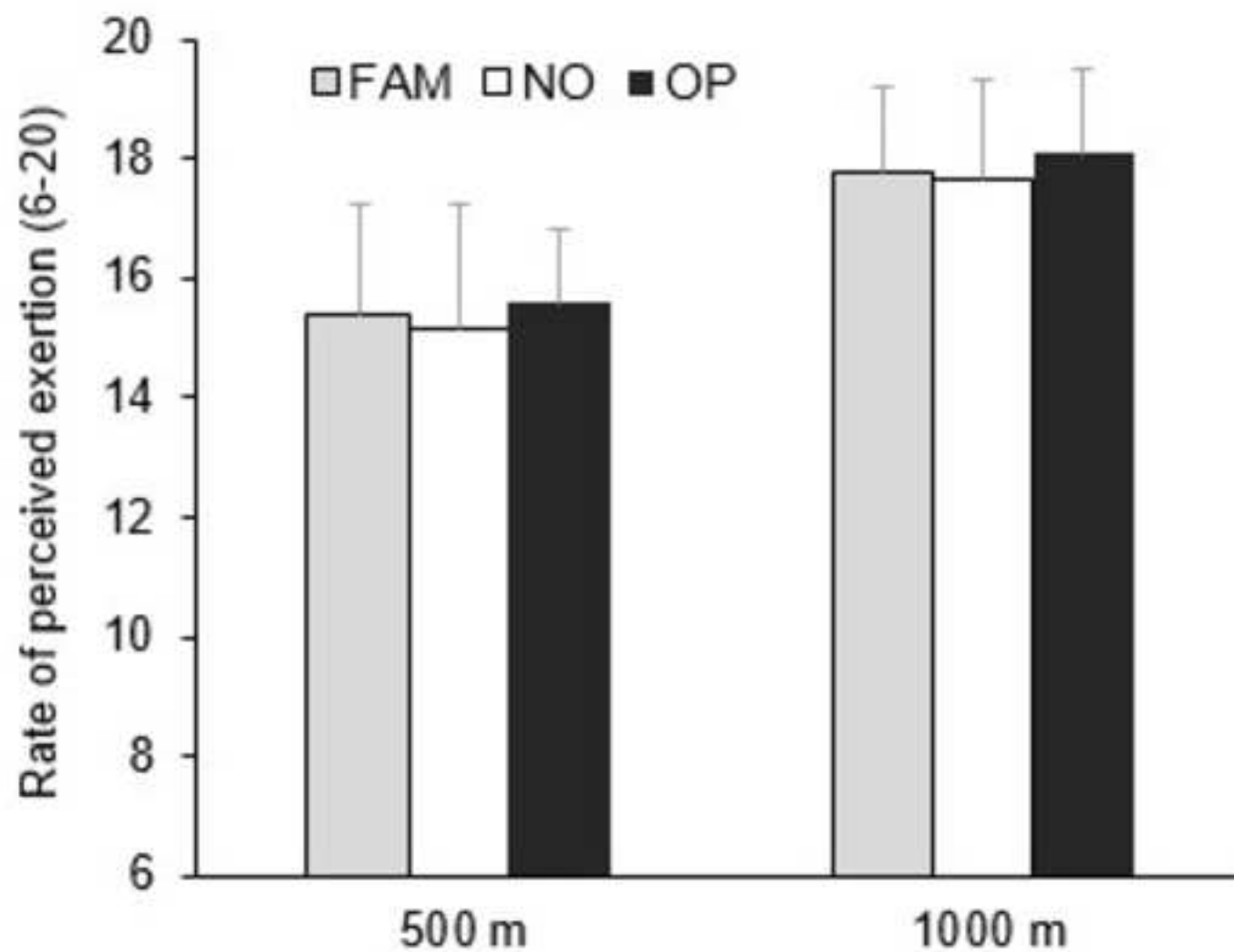
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Page 10, Line 264-266: Check grammar.

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  
7 whether these effects are also present in cycling time trials of shorter duration. Twelve  
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14 W; OP:  $367 \pm 67$ ;  $p = 0.564$ ) were found between the experimental conditions. In  
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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, Zijdewind,  
50 & Hettinga, 2017; Konings, Schoenmakers, Walker, & Hettinga, 2016; Tomazini et al., 2015;



51 Williams, Jones, Sparks, Marchant, et al., 2015; Williams, Jones, Sparks, Midgley, et al.,  
52 2015). The presence of a virtual competitor has been shown to improve performance in 2 km  
53 (Corbett et al., 2012), 4 km (Konings et al., 2017; Konings et al., 2016), 16.1 km (Williams,  
54 Jones, Sparks, Marchant, et al., 2015; Williams, Jones, Sparks, Midgley, et al., 2015), and 20  
55 km cycling time trials (Corbett et al., 2018), as well as in 5 km running time trials (Tomazini  
56 et al., 2015). This performance improvement when racing a competitor has been related to a  
57 decreased internal focus of attention (Williams, Jones, Sparks, Marchant, et al., 2015), higher  
58 anaerobic contribution (Corbett et al., 2012), improved heat tolerance (Corbett et al., 2018),  
59 and the ability to handle higher muscle fatigue without changing perceived exertion (Konings  
60 et al., 2017). In addition, the initial behaviour of a virtual opponent has been revealed to alter  
61 the initial pacing decisions of cyclists, whereas a faster starting opponent evoked a faster initial  
62 pace compared with a slower starting opponent (Konings et al., 2016).

63           Although the improvement in time trial performance in the presence of a virtual  
64 opponent is a consistent finding, all previous studies have examined the impact of a competitor  
65 in time trials with a duration of two minutes or longer. This is of importance, as modelling  
66 studies clearly show that optimal pacing strategies in short duration events differ compared  
67 with events of more prolonged duration (De Koning, Bobbert, & Foster, 1999; De Koning et  
68 al., 2011; Foster et al., 2003; Foster, Hoyos, Earnest, & Lucía, 2005; Hettinga, De Koning,  
69 Hulleman, & Foster, 2012). In short distance events (< 2 minutes), creatine phosphate  
70 depletion is argued to be the main limiting factor, while in longer events (> 2 minutes) rate of  
71 substrate depletion, oxygen consumption, heat accumulation and/or accumulation of fatigue-  
72 related metabolites (i.e. inorganic phosphate, potassium and hydrogen ions) are argued to be  
73 the main limiting factors (Abbiss & Laursen, 2008; Foster, Hoyos, Earnest, & Lucia, 2005;  
74 Tucker, 2009). Consequently, it makes sense that different pacing strategies would fit different  
75 distances. Pacing in long distance events is characterized by a high power output in the  
76 beginning and the end of a race, with a constant power output in between (Foster et al., 2004,  
77 2003). In contrast, to achieve optimal performance in short distance events it has been advised  
78 to adopt a fast starting strategy, with a progressive decrease in power output (De Koning et al.,

79 1999; De Koning, De Groot, & Van Ingen Schenau, 1992; Foster et al., 2004). In this respect,  
80 pacing strategies in 250 m, 500 m, and 1 km cycling trials have shown to be different, and  
81 even in a 250 m trial peak power is still lower than the potential maximal power output,  
82 highlighting the importance of pacing in short time trial events (de Jong et al., 2015). Where  
83 these distance-related differences in optimal pacing have been established, it is yet unknown  
84 if the presence of competitors impacts differently on pacing and performance in the shorter  
85 competitive time trials compared with the more well-researched middle-distance time trials.

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

94

## 95 **Materials and methods**

### 96 *Participants*

97 Fourteen male participants (age:  $24.1 \pm 7.2$  years; body mass:  $80.9 \pm 8.8$  kg; height:  $1.84 \pm$   
98  $0.08$  m) participated in this study. Participants were moderate to highly-physically active as  
99 they engaged in strenuous activity at least twice a week, and had previous experience with  
100 pacing their physical activity during cycling. All participants were experienced to cycling at a  
101 moderate to high-intensity, although cycling was for most of them not their first sport. Because  
102 of concerns in regards to motivation in some of the time trials, two participants have been  
103 excluded out of the analysis. Before taking part, all participants provided informed consent  
104 and completed a pre-activity readiness questionnaire (PAR-Q (Cardinal, Esters, & Cardinal,  
105 1996)). The study was approved by the University of Essex local ethical committee in  
106 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

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

167 \*\*\*\*\*Table 1 near here\*\*\*\*\*

168 \*\*\*\*\*Figure 1 near here\*\*\*\*\*

169

170 Mean power outputs per kilometre are shown in Figure 1. A main effect for segment  
171 ( $F = 15.05$ ;  $p < 0.001$ ;  $d = 0.55$ ), but not for condition ( $F = 0.588$ ;  $p = 0.564$ ;  $d = 0.14$ ) was  
172 found. No interaction effect for condition x segment ( $F = 1.769$ ;  $p = 0.199$ ;  $d = 0.26$ ) was  
173 revealed, indicating no differences in pacing profile between conditions. Finally, cadence  
174 showed a main effect for segment ( $F = 46.52$ ;  $p < 0.001$ ;  $d = 0.69$ ), indicating differences in  
175 chosen cadence over the race. Post-hoc analysis revealed a lower cadence between 0-250 m  
176 ( $98 \pm 12$  rpm; all  $p < 0.01$ ) compared with the other 250 m segments, and a higher cadence  
177 between 250-500 m ( $117 \pm 14$  rpm, all  $p < 0.01$ ) compared with all other 250 m segments.  
178 Cadence did not differ between the 500-750 m ( $112 \pm 14$  rpm) and 750-1000 m segments ( $110$   
179  $\pm 16$  rpm;  $p = 0.302$ ;  $d = 0.13$ ). No main effect for condition ( $F = 1.973$ ;  $p = 0.183$ ;  $d = 0.14$ )  
180 and no condition x segment interaction effect ( $F = 0.713$ ;  $p = 0.527$ ;  $d = 0.17$ ) were found.

181 Mean ( $\pm$ SD) reported RPE scores after 500 m and directly after finishing the time trial  
182 per experimental condition are shown in Figure 2. A main effect for distance ( $F = 92.59$ ;  $p <$   
183  $0.001$ ;  $d = 1.49$ ), but not for condition ( $F = 0.314$ ;  $p = 0.627$ ;  $d = 0.16$ ) were found. No  
184 interaction effect for condition x distance ( $F = 0.186$ ;  $p = 0.831$ ;  $d = 0.17$ ) was revealed.

185

186 \*\*\*\*\*Figure 2 near here\*\*\*\*\*

187

## 188 Discussion

189 The aim of the present study was to discover whether the influence of an opponent would alter  
190 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

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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.

	<b>FAM</b>	<b>NO</b>	<b>OP</b>
<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 <sup>1</sup>	108 $\pm$ 34 (87 - 129)	97 $\pm$ 27 (80 - 113)
Mean absolute error estimated finishing time (s)	X <sup>1</sup>	25 $\pm$ 27 (8 - 43)	22 $\pm$ 16 (12 - 32)

<sup>1</sup> 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

1 **Head-to-head competition does not affect pacing or**  
2 **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:  $91.5 \pm 7.7$  s; NO:  $91.6 \pm 6.4$   
30 s; OP:  $90.9 \pm 4.9$  s;  $p = 0.907$ ) or power output (FAM:  $382 \pm 111$  W; NO:  $363 \pm 80$   
31 W; OP:  $367 \pm 67$ ;  $p = 0.564$ ) 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**

1  
2 41 Pacing strategy is a key factor that affects the optimal performance of athletes (Abbiss &  
3  
4 42 Laursen, 2008; Edwards & Polman, 2013; Foster, Hoyos, Earnest, & Lucía, 2005). When  
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6 43 employing a sub-optimal pacing strategy, athletes may expend a considerable amount of  
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8 44 energy too fast, burning out before the finish and risking injury. Conversely, they may finish  
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10 45 the event with reserves still left, but with a lower finishing position than they had the potential  
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12 46 to achieve (Abbiss & Laursen, 2008; Foster, Hoyos, Earnest, & Lucía, 2005; Thiel, Foster,  
13  
14 47 Banzer, & De Koning, 2012). A better understanding of factors that influence the pacing  
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16 48 decision-making process could help develop more effective pacing strategies to use for athletes  
17  
18 49 and coaches in training and competition, and lead to more effective training protocols and  
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20 50 subsequent competitive success (Edwards & Polman, 2013; Smits, Pepping, & Hettinga,  
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22 51 2014).

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26 52 Pacing can be defined as a decision-making process about the goal-directed regulation  
27  
28 53 of exercise intensity over an exercise bout in which athletes decide how and when to invest  
29  
30 54 their energy (Edwards & Polman, 2013; Renfree, Martin, Micklewright, & St Clair Gibson,  
31  
32 55 2014; Smits et al., 2014). Until recently, research has focused mostly on internal factors that  
33  
34 56 affect pacing decisions, such as physiology and biomechanics in time trials (Smits et al., 2014).  
35  
36 57 Most sports, however, involve head-to-head competition in which pacing strategies are likely  
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38 58 influenced by external factors as well (Hettinga, Konings, & Pepping, 2017; Konings &  
39  
40 59 Hettinga, 2018; Smits et al., 2014). In this respect, the importance of athlete-environment  
41  
42 60 interactions in the context of pacing, such as the interaction between competitors, have been  
43  
44 61 recently emphasized (Hettinga et al., 2017; Konings & Hettinga, 2018; McCormick, Meijen,  
45  
46 62 & Marcora, 2015; Smits et al., 2014; Venhorst, Micklewright, & Noakes, 2017).

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49 63 The controlled situation of a laboratory cycling time trial experiment has proven to  
50  
51 64 be an effective method to explore the environmental influence of a competitor on pacing  
52  
53 65 behaviour and performance over a range of time trial distances (Corbett, Barwood,  
54  
55 66 Ouzounoglou, Thelwell, & Dicks, 2012; Corbett et al., 2018; Konings, Parkinson, Zijdewind,  
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57 67 & Hettinga, 2017; Konings, Schoenmakers, Walker, & Hettinga, 2016; Tomazini et al., 2015;

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68 Williams, Jones, Sparks, Marchant, et al., 2015; Williams, Jones, Sparks, Midgley, et al.,  
69 2015). The presence of a virtual competitor has been shown to improve performance in 2 km  
70 (Corbett et al., 2012), 4 km (Konings et al., 2017; Konings et al., 2016), 16.1 km (Williams,  
71 Jones, Sparks, Marchant, et al., 2015; Williams, Jones, Sparks, Midgley, et al., 2015), and 20  
72 km cycling time trials (Corbett et al., 2018), as well as in 5 km running time trials (Tomazini  
73 et al., 2015). This performance improvement when racing a competitor has been related to a  
74 decreased internal focus of attention (Williams, Jones, Sparks, Marchant, et al., 2015), higher  
75 anaerobic contribution (Corbett et al., 2012), improved heat tolerance (Corbett et al., 2018),  
76 and the ability to handle higher muscle fatigue without changing perceived exertion (Konings  
77 et al., 2017). In addition, the initial behaviour of a virtual opponent has been revealed to alter  
78 the initial pacing decisions of cyclists, whereas a faster starting opponent evoked a faster initial  
79 pace compared with a slower starting opponent (Konings et al., 2016).

80           Although the improvement in time trial performance in the presence of a virtual  
81 opponent is a consistent finding, all previous studies have examined the impact of a competitor  
82 in time trials with a duration of two minutes or longer. This is of importance, as modelling  
83 studies clearly show that optimal pacing strategies in short duration events differ compared  
84 with events of more prolonged duration (De Koning, Bobbert, & Foster, 1999; De Koning et  
85 al., 2011; Foster et al., 2003; Foster, Hoyos, Earnest, & Lucía, 2005; Hettinga, De Koning,  
86 Hulleman, & Foster, 2012). In short distance events (< 2 minutes), creatine phosphate  
87 depletion is argued to be the main limiting factor, while in longer events (> 2 minutes) rate of  
88 substrate depletion, oxygen consumption, heat accumulation and/or accumulation of fatigue-  
89 related metabolites (i.e. inorganic phosphate, potassium and hydrogen ions) are argued to be  
90 the main limiting factors (Abbiss & Laursen, 2008; Foster, Hoyos, Earnest, & Lucia, 2005;  
91 Tucker, 2009). Consequently, it makes sense that different pacing strategies would fit different  
92 distances. Pacing in long distance events is characterized by a high power output in the  
93 beginning and the end of a race, with a constant power output in between (Foster et al., 2004,  
94 2003). In contrast, to achieve optimal performance in short distance events it has been advised  
95 to adopt a fast starting strategy, with a progressive decrease in power output (De Koning et al.,

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96 1999; De Koning, De Groot, & Van Ingen Schenau, 1992; Foster et al., 2004). In this respect,  
97 pacing strategies in 250 m, 500 m, and 1 km cycling trials have shown to be different, and  
98 even in a 250 m trial peak power is still lower than the potential maximal power output,  
99 highlighting the importance of pacing in short time trial events (de Jong et al., 2015). Where  
100 these distance-related differences in optimal pacing have been established, it is yet unknown  
101 if the presence of competitors impacts differently on pacing and performance in the shorter  
102 competitive time trials compared with the more well-researched middle-distance time trials.

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

111

## 112 **Materials and methods**

### 113 *Participants*

114 Fourteen male participants (age:  $24.1 \pm 7.2$  years; body mass:  $80.9 \pm 8.8$  kg; height:  $1.84 \pm$   
115  $0.08$  m) participated in this study. Participants were moderate to highly-physically active as  
116 they engaged in strenuous activity at least twice a week, and had previous experience with  
117 pacing their physical activity during cycling. All participants were experienced to cycling at a  
118 moderate to high-intensity, although cycling was for most of them not their first sport. Because  
119 of concerns in regards to motivation in some of the time trials, two participants have been  
120 excluded out of the analysis. Before taking part, all participants provided informed consent  
121 and completed a pre-activity readiness questionnaire (PAR-Q (Cardinal, Esters, & Cardinal,  
122 1996)). The study was approved by the University of Essex local ethical committee in  
123 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

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

184 \*\*\*\*\*Table 1 near here\*\*\*\*\*

185 \*\*\*\*\*Figure 1 near here\*\*\*\*\*

186

187 Mean power outputs per kilometre are shown in Figure 1. A main effect for segment  
188 ( $F = 15.05$ ;  $p < 0.001$ ;  $d = 0.55$ ), but not for condition ( $F = 0.588$ ;  $p = 0.564$ ;  $d = 0.14$ ) was  
189 found. No interaction effect for condition x segment ( $F = 1.769$ ;  $p = 0.199$ ;  $d = 0.26$ ) was  
190 revealed, indicating no differences in pacing profile between conditions. Finally, cadence  
191 showed a main effect for segment ( $F = 46.52$ ;  $p < 0.001$ ;  $d = 0.69$ ), indicating differences in  
192 chosen cadence over the race. Post-hoc analysis revealed a lower cadence between 0-250 m  
193 ( $98 \pm 12$  rpm; all  $p < 0.01$ ) compared with the other 250 m segments, and a higher cadence  
194 between 250-500 m ( $117 \pm 14$  rpm, all  $p < 0.01$ ) compared with all other 250 m segments.  
195 Cadence did not differ between the 500-750 m ( $112 \pm 14$  rpm) and 750-1000 m segments ( $110$   
196  $\pm 16$  rpm;  $p = 0.302$ ;  $d = 0.13$ ). No main effect for condition ( $F = 1.973$ ;  $p = 0.183$ ;  $d = 0.14$ )  
197 and no condition x segment interaction effect ( $F = 0.713$ ;  $p = 0.527$ ;  $d = 0.17$ ) were found.

198 Mean ( $\pm$ SD) reported RPE scores after 500 m and directly after finishing the time trial  
199 per experimental condition are shown in Figure 2. A main effect for distance ( $F = 92.59$ ;  $p <$   
200  $0.001$ ;  $d = 1.49$ ), but not for condition ( $F = 0.314$ ;  $p = 0.627$ ;  $d = 0.16$ ) were found. No  
201 interaction effect for condition x distance ( $F = 0.186$ ;  $p = 0.831$ ;  $d = 0.17$ ) was revealed.

202

203 \*\*\*\*\*Figure 2 near here\*\*\*\*\*

204

## 205 Discussion

206 The aim of the present study was to discover whether the influence of an opponent would alter  
207 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



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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.

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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.

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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.

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411 **Tables**

1  
2 **Table 1.** Mean  $\pm$  SD (95% confidence intervals) power output, actual and estimated finishing  
3 time and cadence per experimental condition. In addition, the mean absolute error of estimated  
4 finishing times versus actual finishing times in seconds.  
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	FAM	NO	OP
<b>Performance</b>			
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)
<b>Time perception</b>			
Estimated finishing time (s)	X <sup>1</sup>	108 $\pm$ 34 (87 - 129)	97 $\pm$ 27 (80 - 113)
Mean absolute error estimated finishing time (s)	X <sup>1</sup>	25 $\pm$ 27 (8 - 43)	22 $\pm$ 16 (12 - 32)

<sup>1</sup> 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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