

Athlete-opponent interdependency alters pacing and information-seeking behavior.

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ABSTRACT

PURPOSE. The influence of interdependency between competitors on pacing decision-making and information-seeking behavior has been explored. This has been done by only altering instructions, and thereby action possibilities, while controlling environment (i.e. competitor behavior) and exercise task. **METHODS.** Twelve participants performed a 4-km time-trial on a Velotron cycle ergometer in a randomized, counterbalanced order alone with no virtual opponent (NO), against a virtual opponent with no restrictions (low athlete-opponent interdependency; OP-IND), or against a virtual opponent who the participant was permitted to overtake only once during the trial (high athlete-opponent interdependency; OP-DEP). Information-seeking behavior was evaluated using an SMI Eye tracker. Differences in pacing, performance and information-seeking behavior were examined using repeated-measures ANOVA ($p < 0.05$). **RESULTS.** Neither mean power output (NO: 298 ± 35 W; OP-IND: 297 ± 38 W; OP-DEP: 296 ± 37 W) nor finishing time (NO: 377.7 ± 17.4 sec; OP-IND: 379.3 ± 19.5 sec; OP-DEP: 378.5 ± 17.7 sec) differed between experimental conditions. However, power output was lower in the first kilometer of OP-DEP compared to the other experimental conditions (NO: 332 ± 59 W; OP-IND: 325 ± 62 W; OP-DEP: 316 ± 58 W; both $p < 0.05$), and participants decided to wait longer before they overtook their opponent (OP-IND: 137 ± 130 sec; OP-DEP: 255 ± 107 sec; $p = 0.040$). Moreover, total fixation time spent on the avatar of the virtual opponent increased when participants were only allowed to overtake once (OP-IND: 23.3 ± 16.6 sec; OP-DEP: 55.8 ± 32.7 sec; $p = 0.002$). **CONCLUSION.** A higher interdependency between athlete and opponent altered pacing behavior in terms of in-race adaptations based on opponent's behavior, and induced an increased attentional focus on the virtual opponent. Thus, in the context of exercise regulation, attentional cues are likely to be used in an adaptive way according to their availability and situational relevance, consistent with a decision-making framework based on the interdependence of perception and action.

KEYWORDS: pacing strategy, attentional focus, gaze analysis, sport performance

1 1. INTRODUCTION

2 **Paragraph Number 1** - As energy resources are limited in human beings, exercisers
3 are required to decide continuously about how and when to use their available amount of energy
4 (1). In this pacing decision-making process, the interaction between the athlete and their
5 surroundings appears to be crucial (1–3). In this sense, although there are multiple external
6 variables that present social invitations for action to an athlete, opponents are arguably one of
7 the most crucial ones in competitive sports (2). Previously, experimental studies have already
8 shown that a virtual opponent could improve performance (4–8), and alter initial pace (7).

9 **Paragraph Number 2** - It is also well known that pacing behavior varies between event
10 types. Specific demands of a sport, such as favorable positioning, competing for the optimal
11 line, and minimizing fall risk, could draw athletes away from the energetically favorable
12 strategies from individual perspective without taking into account the context around this
13 individual and may alter the relevant external cues (2). That is, paying close attention to external
14 cues is likely an important aspect of reading a competitor or a competitive situation. A main
15 underlying mechanism behind these differences in pacing behavior and external attentional
16 focus between competitive sports could be a varying interdependency between the competitors.
17 For example, the possibility of drafting, and the magnitude of associated energy-saving effects
18 of drafting, appeared to be an important determinant for pacing behavior and tactical decision-
19 making in competitive sports (2, 9, 10). These energy-saving effects of drafting could in fact be
20 perceived as a higher interdependency between athlete and opponent.

21 **Paragraph Number 3** - The present study explored the influence of interdependency
22 between competitors on the decision-making process involved in pacing. This has been done
23 by only altering instructions, and thereby action possibilities, while controlling the environment
24 (e.g. competitor behavior) and exercise task. In addition, the analysis of gaze behavior provided
25 a novel opportunity to analyze the information-seeking behavior of exercisers and the relation

26 to pacing decisions. Up until now, eye-tracking technology to examine gaze and pacing
27 behavior has only been used during individual time trial exercise (11), but not yet in a scenario
28 involving competitors. Therefore, we examined in this study whether the same opponent, but a
29 different interdependency between the athlete and the opponent, affected exercise regulation
30 and information-seeking behavior in laboratory-controlled conditions. It was hypothesized that
31 a higher interdependency between athlete and opponent would evoke different pacing decisions,
32 in response to the opponent's pacing behavior, and would alter the information-seeking
33 behavior of the exerciser. We hypothesized an increased focus on the competitor, at the cost of
34 attentional focus on other external information such as velocity, cadence or time, when
35 interdependency between competitors is higher. This would indicate that exercisers use
36 different external information in order to pace themselves based on the competitive situation.

37

38 2. METHODS

39 *2.1 Participants*

40 **Paragraph Number 4** - 12 participants with at least two years of cycling experience
41 with training at a moderate to high intensity (age: 45.8 ± 7.0 years; body mass: 78.7 ± 10.4 kg;
42 height: 176.6 ± 7.4 cm) participated in this study. All participants were moderately to highly
43 physically active (two or more moderate to high-intensity training sessions per week) and
44 familiar with pacing their exercise. All participants gave prior written informed consent and
45 completed a health screening questionnaire (Physical Activity Readiness Questionnaire (12)).
46 The study was approved by the ethical committee of the University of Essex in accordance with
47 the Declaration of Helsinki.

48

49 *2.2 Experimental procedures*

50 **Paragraph Number 5** - Participants attended the laboratory on five different occasions,
51 completing a 4-km cycling time trial each visit. Each 4-km time trial was preceded by a 5-min
52 warm-up at a fixed load of 150 W, followed by a 4-min inactive recovery period before starting
53 the time trial. The first two 4-km time trials were used as familiarization trials (FAM1 and
54 FAM2). In the third to fifth visit participants had to perform one of the three experimental 4-
55 km time trials in a randomized, counterbalanced order. The experimental time trials consisted
56 of a 4-km time trial without virtual opponent (NO), a 4-km time trial with virtual opponent,
57 without further instructions (low athlete-opponent interdependency; OP-IND), and a 4-km time
58 trial with virtual opponent including the instruction that the opponent could only be overtaken
59 once by the participant (high athlete-opponent interdependency; OP-DEP).

60 **Paragraph Number 6** - The same opponent was used for both OP-IND and OP-DEP.
61 This opponent was constructed based on the fastest familiarization trial of the participant. In
62 order to maximize the chances the opponent would be in front of the participant directly after
63 the start, yet preventing a too big initial gap between participant and opponent, the opponent
64 was set to adopt an initial pace that led to a 1-second lead after 250 m compared to the fastest
65 familiarization trial of the participant. Hereafter, the opponent adopted a pace of 95% of the
66 power output as achieved in the fastest familiarization trial.

67 **Paragraph Number 7** - Before every time trial, participants were instructed to provide
68 maximal effort. No verbal coaching or motivation was given to the participants during any of
69 the trials. Participants were told that their opponent would be of similar level of performance to
70 simulate a competitive situation where participants perceived their chances of success to be
71 realistic. Time trials were completed at the same time of the day (\pm 2 hours) to minimize
72 circadian variation (13, 14), and 3–7 days apart to limit training adaptations. Participants were
73 asked to maintain normal activity and sleep pattern throughout the testing period. In addition,
74 participants were asked to refrain from any strenuous exercise and alcohol consumption in the

75 preceding 24 hours, and from caffeine and food consumption respectively, four and two hours
76 before the start of the test. Participants were informed that the study was examining cycling
77 performance during 4-km time trials. To prevent any pre-meditated influence on preparation or
78 pre-exercise state, the specific feedback presented for each trial was only revealed immediately
79 before the start of the time trial. All trials were conducted in ambient temperatures between 18-
80 21°C.

81

82 *2.3 Apparatus*

83 **Paragraph Number 8** - Time trials were performed on an advanced cycle ergometer
84 (Velotron Dynafit, Racermate, Seattle, USA), a reliable and valid device for measuring cycling
85 performance and pacing behavior. Using the Velotron 3D software, a flat 4-km time trial course
86 with no wind was programmed and projected onto a large screen in front of the participants for
87 all trials. The cycle ergometer was positioned such that screen itself was offset to the right of
88 the natural forward field of vision of the cyclists. Offsetting the screen in this way required
89 participants to rotate their neck to look at the projected information, thus adding confidence that
90 the eye-tracking measurements constituted deliberate attempts to acquire information, rather
91 than information glances just because it happened to fall naturally within participant's forward
92 field of vision. Notwithstanding minor projector repositioning variances, the projected screen
93 size was 2.1 m wide by 1.5 m high with the bottom border of the projection running 1 m above
94 and parallel to the floor. The cycle ergometer was positioned such that the handlebar stem riser
95 was 3 m perpendicular to the plane of the screen. An A0 sized RPE scale was also displayed to
96 the left of the projector screen clearly visible to the participants while sitting on the cycle
97 ergometer. Prior to the start of each time trial, participants gave a confirmatory answer when
98 asked if all displayed information was clearly visible for them while sitting on the cycle
99 ergometer. Incorporated into the projection beneath the simulated time-trial video, were five

100 fields of real-time feedback information which, presented from left to right, were speed (km.hr-
101 1), elapsed distance (km), pedaling cadence (r.min-1), heart rate (b.min-1) and gearing. In
102 addition, elapsed time (min:sec) was displayed right above the gearing field (see Figure 1).
103 Furthermore, in all time-trials a virtual avatar of the participant was projected onto the screen.
104 In OP-IND and OP-DEP a virtual avatar of an opponent was projected onto the screen as well.
105 The virtual opponent was in this case always visible on the left side of the road, while the virtual
106 avatar of the participant itself was projected onto the right side of the road. This was also clearly
107 communicated to the participants prior to the time trial. The course was projected in helicopter
108 view (see Figure 1) to ensure both virtual avatars were visible to the participant throughout the
109 whole trial, regardless whether the participant was riding in front or behind. Angular separation
110 of the information fields was well beyond the manufacturer-defined eye-tracker spatial
111 resolution of 0.1° and gaze position accuracy within the nearest degree. The separation of the
112 projected information blocks therefore facilitated clear differentiation in eye-tracker
113 measurements.

114 **Paragraph Number 9** - Participants started every trial in the same gear but were free
115 to change their gear ratio throughout the time trial. Power output, velocity, distance, cadence,
116 and gearing were recorded continuously during each trial (sample frequency=4 Hz). In addition,
117 heart rate was monitored every second (Polar M400, Polar Inc.). Rating of perceived exertion
118 (RPE) on a Borg-scale of 6-20 (15) was asked after the warm-up, after each kilometer during
119 the time trial, and directly after passing the finish line.

120

121 *2.4 Information-seeking behavior*

122 **Paragraph Number 10** - All participants wore a glasses-based mobile binocular eye-
123 tracking device (SensoMotoric Instruments SMI eye-tracking glasses; Sensomotoric
124 Instruments, Tetlow, Germany) during the experimental time trial conditions to capture their

125 eye movements during the time trial. The system tracks eye movements using pupil and corneal
126 reflex so that each participant's point of regard can be superimposed onto the recorded scene,
127 thus enabling timed measurements to be made of eye fixations. The SMI eye-tracking glasses
128 were calibrated using a 3-point calibration before starting to record. Eye position was recorded
129 at 60 Hz, which was then down-sampled to 30 frames per second for the resulting scene videos.

130 **Paragraph Number 11** - SMI BeGaze Analysis Software was used to code eye
131 fixations on objects of interest during NO, OP-DEP and OP-IND. The eye-tracking videos for
132 these trials were reviewed and manually coded by the first author using SMI Semantic Gaze
133 Mapping. This procedure allowed us to determine the periods of time spent inspecting each of
134 the regions of interest, in which eye fixation times were recorded in milliseconds against eleven
135 predetermined categories. Six of the categories related to information feedback that were speed,
136 elapsed distance, cadence, heart rate, gearing, and elapsed time. Eye fixation times were also
137 recorded for the rating of perceived exertion poster, the video simulation of the time-trial course
138 that was projected onto the wall (excluding the cycling avatars), the virtual cycling avatar
139 representing the participant itself, and the virtual cycling avatar of the virtual opponent. A final
140 category was created to capture all other objects of regard not corresponding to the other ten
141 categories, for example, when participants looked at the laboratory floor or at laboratory
142 equipment. Only fixations were included into the analyses. This procedure allowed detailed
143 coding of point of regard for the whole length of the time trial, however whereas periods of
144 blinks and saccades were excluded out of the analyses, time trial duration does not equal total
145 fixation time spent. In order to evaluate the total fixation time over the time-trial and between
146 conditions a Total variable was created representing the sum of all of the above-mentioned
147 categories. For all categories both time fixation spent in seconds as well as the total number of
148 fixations were determined for the whole time trial and for each kilometer segment.

149 **Paragraph Number 12** - Directly after finishing OP-DEP, a retrospective think aloud
150 protocol was used to gather qualitative information on the participants intents and reasoning
151 around the overtake of the virtual competitor. This involved the 30 seconds prior to and 30
152 seconds after the overtake. A video replay of the projected screen in this minute was shown to
153 the participant as a visual reminding stimulus, and participants were instructed to recall as much
154 information as possible from this period.

155

156 *2.5 Data analysis*

157 **Paragraph Number 13** - Mean power output, cadence, heart rate and finish time were
158 determined in order to examine performance. Differences in performance between conditions
159 were assessed using a repeated-measures ANOVA. To assess differences in pacing behavior
160 between the conditions, average power output, cadence, heart rate and split times for each 1-
161 km segment were calculated, and differences were tested using a two-way repeated-measures
162 ANOVA (condition × segment). Post-hoc tests with Bonferroni correction were performed
163 when significant results were found. Information-seeking behavior was assessed using the total
164 fixation time and the total number of fixations for each object of interest over the whole time
165 trial and per kilometer. Differences in information-seeking behavior were tested using a two-
166 way repeated-measures ANOVA (condition × segment). All analyses were performed using
167 SPSS 19.0, and significance was accepted at $P < 0.05$.

168

169 3. RESULTS

170 *3.1 Performance analysis*

171 **Paragraph Number 14** - Mean (\pm SD) finishing time, power output, heart rate, and
172 cadence for the three experimental time trial conditions are shown in Table 1. No main effects

173 were found for finishing time ($F=0.428$; $p=0.569$), power output ($F=0.384$; $p=0.605$), heart rate
174 ($F=0.389$; $p=0.682$), or cadence ($F=0.509$; $p=0.608$).

175

176 *3.2 Pacing analysis*

177 **Paragraph Number 15** - Mean power outputs per kilometer are shown in Figure 2. A
178 main effect for segment ($F=8.3$; $p=0.003$), but not for condition ($F=0.4$; $p=0.605$) was found.
179 An interaction effect for condition \times segment ($F=2.3$; $p=0.042$) was revealed, indicating
180 differences in pacing profile between conditions. Post hoc analysis revealed a higher power
181 output during the first kilometer in NO compared to OP-DEP ($p=0.015$), and a higher power
182 output during the first kilometer in OP-IND compared to OP-DEP ($p=0.042$). No differences in
183 pacing were shown between NO and OP-IND. During OP-IND power output of the participants
184 in the initial 250 meters was on average 9.8% above the mean power output of the trial. During
185 OP-DEP this was on average 5.6%.

186 **Paragraph Number 16** - A main effect of segment on heart rate ($F=196.1$; $p<0.001$),
187 but neither a main effect for condition ($F=0.4$; $p=0.682$) nor an interaction effect condition \times
188 segment ($F=0.7$; $p=0.521$) were observed. No main effect for cadence for condition ($F=0.5$;
189 $p=0.608$) or segment ($F=1.8$; $p=0.195$), and no interaction effect for condition \times segment
190 ($F=1.0$; $p=0.397$) was found.

191 **Paragraph Number 17** - Mean RPE scores per kilometer for each experimental
192 condition are shown in Table 1. A main effect for segment ($F=297.1$; $p<0.001$) was reported,
193 but no main effect for condition ($F=0.8$; $p=0.448$) was found. In addition, an interaction effect
194 for condition \times segment ($F=2.2$; $p=0.038$) was revealed. Post hoc analysis indicated a higher
195 RPE score after three kilometer in NO compared to OP-DEP ($p=0.003$), and a higher RPE score
196 after three kilometer in OP-IND compared to OP-DEP ($p=0.023$). No differences in RPE were
197 found between NO and OP-IND.

198

199 *3.3 Information-seeking analyses*

200 **Paragraph Number 18** - Mean fixation time spent and the number of fixations in total
201 and per categorized variable per experimental condition over the whole trial are shown in Table
202 2. Analysis revealed a main effect of condition on the mean fixation time spent on the Rider
203 ($F=9.8$; $p=0.005$) and the Opponent ($F=15.5$; $p=0.002$), as well as on information about
204 Velocity ($F=5.7$; $p=0.010$) and Cadence ($F=5.2$; $p=0.014$), and Total ($F=5.7$; $p=0.010$). Post-
205 hoc analysis revealed an increased focus on the avatar of the rider during OP-IND compared to
206 NO ($p=0.013$), and during OP-DEP compared to NO ($p<0.001$), but no difference between OP-
207 DEP and OP-IND ($p=0.870$). Time fixating on the virtual opponent was much higher in OP-
208 DEP compared to OP-IND ($p=0.002$). Participants showed a decreased focus on the velocity
209 feedback during OP-IND compared to NO ($p=0.028$), and during OP-DEP compared to NO
210 ($p=0.014$). A decreased amount of time was spent fixating on the cadence feedback in OP-DEP
211 compared to NO ($p=0.007$). Finally, when taking all variables together total fixation time spent
212 over the whole trial was higher in OP-DEP compared to NO ($p=0.008$), and in OP-DEP
213 compared to OP-IND ($p=0.031$). No effect for condition was reported for any of the other
214 categories.

215 **Paragraph Number 19** - A main effect for segment was revealed for Rider ($F=4.4$;
216 $p=0.024$), Opponent ($F=23.1$; $p<0.001$), Velocity ($F=6.5$; $p=0.023$), Cadence ($F=3.7$; $p=0.021$),
217 Gearing ($F=6.4$; $p=0.014$), RPE ($F=12.0$; $p<0.001$), Other ($F=4.5$; $p=0.034$), and Total ($F=21.8$;
218 $p<0.001$). Post-hoc analysis revealed a decline in the time spent fixating on all these variables
219 over the race, except Other and RPE. Time spent fixating on Other increased per kilometer,
220 while time spent fixating on RPE is higher from the 1st until the 3rd kilometer, likely related to
221 the moment of asking RPE after each kilometer. No effect for segment was found for any of
222 the other categories.

223 **Paragraph Number 20** - An interactive effect for condition \times segment was revealed
224 for Opponent ($F=6.0$; $p=0.002$), and Screen ($F=4.7$; $p<0.001$). Yet, participants still spent more
225 time fixating on the opponent in every kilometer during OP-DEP compared to OP-IND (all
226 $p<0.05$; e.g. 1st km: OP-IND= 7.8 ± 3.9 and OP-DEP= 17.4 ± 8.4 sec; 4th km: OP-IND= 3.7 ± 3.9 sec
227 and OP-DEP= 7.7 ± 6.9 sec). In addition, the number of fixations on Opponent showed a steady
228 decline per kilometer during OP-IND, while in OP-DEP there is only a decline in the number
229 of fixations in the 4th kilometer compared to the 3th kilometer. Finally, participants spent less
230 time fixating on the screen (excluding avatars) in the first two kilometers of OP-DEP compared
231 to NO ($p=0.041$ and $p=0.024$, respectively). No interaction effect was found for any of the other
232 categories.

233

234 *3.4 Overtaking analysis and outcomes talk aloud procedure*

235 **Paragraph Number 21** - 9 out of 12 participants were able to overtake their opponent
236 in both OP-IND and in OP-DEP, while 2 participants only overtook their opponent in OP-IND
237 and 1 participant only overtook his opponent in OP-DEP. In this sense, all participants proved
238 to be able to overtake (and beat) their opponent at least once. The average number of overtakes
239 was 0.9 ± 0.3 in OP-IND and 0.8 ± 0.4 in OP-DEP ($p=0.586$). Participants decided to wait longer
240 before they first overtook their opponent in OP-DEP (overtake at $67\pm28\%$ of race completion)
241 compared to OP-IND (overtake at $36\pm34\%$ of race completion; $p=0.040$). Mean fixation time
242 spent per categorized variables prior and after the overtake took place, normalized for duration
243 in percentages, can be found in Figure 3. The information-seeking behavior during the 10
244 seconds prior to the overtake of the virtual opponent in OP-DEP can be found in Table 3.

245 **Paragraph Number 22** - The retrospective talk aloud procedure revealed that velocity,
246 (remaining) distance, and the virtual opponent were the most important cues of information for
247 participants regarding the overtaking decision. In this respect, 9 out of 10 participants who

248 overtook their virtual opponent in OP-DEP mentioned that they decided to overtake their
249 opponent when they perceived themselves capable to cover the remaining distance without
250 significant deceleration.

251

252 4. DISCUSSION

253 **Paragraph Number 23** - The present study examined how a difference in the
254 interdependency between the athlete and the opponent would affect exercise regulation and
255 information-seeking behavior. It appeared that cyclists adopted a slower initial pace and
256 decided to wait longer before overtaking their opponent when they became more dependent on
257 their competitor. Furthermore, a difference in information-seeking behavior was revealed. That
258 is, participants were looking for different information in OP-DEP, mainly due to an increased
259 focus on the avatars of themselves and their opponents, while focusing less on their velocity
260 and cadence feedback.

261 **Paragraph Number 24** - These outcomes highlight the importance of one's perceived
262 action possibilities in pacing decision-making, whereas a rather simple alteration in instructions
263 impacting on perceived interdependency already alters pacing behavior. In this respect, many
264 traditional theoretical frameworks about pacing regulation have argued that athletes use RPE
265 and the endpoint information to make pacing-related decisions (16, 17). The analysis of gaze
266 behavior provides a novel opportunity to analyze the actual information-seeking behavior of
267 exercisers and its relation to pacing regulation (11). This has revealed in the present study that
268 attentional cues are used in a much more adaptive way according to their availability, relevance
269 to their position in the race and relevance to what it is they are trying to achieve (i.e. to beat a
270 competitor, to get a particular position, to simply finish, to achieve a PB etc.) than previously
271 has been suggested in the decision-making process involved in pacing (18).

272 **Paragraph Number 25** - In line with previous research (6, 11, 19–21), our findings
273 suggest a decline in attentional focus on external information over the race, indicated by the
274 reduction in total fixation time spent and the number of fixations over the race for most of the
275 variables. A notable exception in this case is the increase in number of fixations at the distance
276 feedback in the final kilometer compared to prior in the race. A similar finding was reported by
277 Whitehead et al. (21) using a think aloud procedure, showing an increased number of
278 verbalizations related to distance in the last quartile of 16.1 km cycling time trials. In this study
279 the deliberate decision was made to not include power output as source of external information,
280 despite the fact that power output can be a potential valuable source of external information for
281 cyclists. This decision was made because the authors wanted to make sure that each provided
282 source of external information would be clearly different from the others. As such, in the given
283 experimental situation we felt that velocity and power output would give a similar type of
284 information to our participants. The decision to include velocity rather than power output was
285 made due to the expectation that all our participants would likely be familiar with velocity
286 feedback in the context of cycling.

287 **Paragraph Number 26** - The presence of a virtual competitor led to an increased focus
288 on the avatar of the participant itself, and decreased attentional focus on the velocity feedback.
289 In contrast, the manipulation of the interdependency between athlete and opponent mainly
290 affected the attentional focus on the virtual opponent. That is, when participants became more
291 dependent on their opponent the total fixation time at this virtual opponent increased drastically.
292 This finding highlights the importance of perception in relation to action possibilities, whereas
293 the environment and athlete did not differ between OP-DEP and OP-IND. In addition, an
294 increase in the number of fixations, but not in total fixation time spent, on the avatar of the
295 participant itself is noted in the high interdependency condition (OP-DEP), suggesting many
296 glances rather than fewer and longer fixations. This is likely an indication of frequent

297 monitoring of the distance between the avatar of the participant and the avatar of the opponent
298 during the time trial. In addition, time spent fixating on the avatar of the opponent decreased
299 after the overtake compared to prior in OP-DEP, but not in OP-IND.

300 **Paragraph Number 27** - The instruction to allow only one overtake of the virtual
301 opponent in OP-DEP created a recognizable and similar decision-making moment in time for
302 all the participants. In this sense, the time period right before the overtake may provide insight
303 into the information that is used leading to the decision to overtake the other competitor.
304 According to the eye tracking analysis, the most frequently searched information sources in the
305 ten seconds prior to the overtake were both avatars, in combination with the distance feedback.
306 This is supported by the retrospective talk aloud procedure, in which 9 out of 10 participants
307 mentioned that they decided to overtake their opponent when they perceived themselves
308 capable to cover the remaining distance without significant deceleration.

309 **Paragraph Number 28** - In addition to alterations in information-seeking behavior,
310 manipulation of the interdependency between competitors also altered the pacing behavior of
311 the participants. Comparable effects are likely be seen in observational studies looking into
312 pacing strategies during real-life competitions (2). For example, the pacing strategies of athletes
313 are similar to the optimal pacing strategies as predicted in modelling studies when the
314 performance of the individual athlete is relatively independent of the other competitors, such as
315 in time trial sports (22, 23), or sports in which individuals compete in separate lanes (24–27).
316 In contrast, exercisers tend to adjust their pacing behavior based on their competitors when
317 competing in the same lane (9, 10, 28–31). This effect becomes even more apparent when the
318 interdependency between competitors is further increased, for example via the aerodynamic
319 beneficial effect of drafting behind an opponent (e.g. in cycling/speed skating; (9, 29)), or
320 during important events such as the Olympic Games (32). In this perspective, our findings
321 support the hypothesis that the interdependency between competitors could be a crucial

322 promotor for these differences in chosen pacing behavior between different competitive sports.
323 Nevertheless, more research is still needed in this respect in regard to the generalizability of our
324 findings to different ages, levels of fitness and levels or experience.

325 **Paragraph Number 29** - Finally, the presence of a virtual opponent has been shown in
326 previous studies to improve time trial performance (5–8, 33). However, in the present study no
327 such effect was found. This lack of an effect might be related to the received feedback by the
328 participants during the time trials. In particular the timer feedback may have evoked a
329 competitive environment in which the participants were able to start competing against their
330 own previous performance, as they were aware of their own finishing times. Schiphof et al.
331 (unpublished data) showed that the performance effect when riding against a virtual opponent
332 diminished indeed when the same feedback without the timer was presented to trained cyclists.
333 In addition, the constructed virtual avatar in this study was set up to be slightly slower compared
334 to the participant's best familiarization trial (ca. 2-3 seconds) in order to make sure participants
335 were able to overtake their opponent in normal conditions. As a result, simply beating the virtual
336 opponent would not have led to an improvement in performance compared to riding alone.
337 However, in this perspective, previous research has indicated that indicate that the performance
338 level of the competitors does not affect one's own performance (34). Interestingly, the faster
339 initial pace of the opponent did not evoke a noticeable response in the participants when no
340 restrictions were provided to the participant, in contrast to previous findings (7). Again, this
341 finding could likely be related to the received feedback during the time trials in general, and the
342 timer feedback in particular. Interestingly, RPE was lower after the third kilometer in OP-DEP
343 compared to the other experimental conditions. This could be related to the slower initial pace
344 in OP-DEP, however, also the increased attentional focus on external sources in OP-DEP could
345 have affected reported RPE.

346 **Paragraph Number 30** - Participants were not explicitly asked if they believed they
347 were competing against an actually opponent or an avatar. Nevertheless, based on the
348 experiences of the experimenter during the data collection, there were strong indications that
349 the participants did believe that the pacing and performance of the avatar was based on a “real-
350 life” performance, despite being aware that what they saw on the screen was a virtual avatar
351 (i.e. we did not attempt in any way to create an illusion that a second person was cycling at the
352 same time behind a curtain or in a different room).

353

354 5. CONCLUSION

355 **Paragraph Number 31** - Our findings highlight that the pacing and information-
356 seeking behavior of exercisers during time trial exercise depends on the circumstances in which
357 the exerciser has to act, which is consistent with the adaptive cue utilization and decision-
358 making processes previously suggested (2, 3, 18). The presence of competition, and even the
359 relationship between the competitors in this competition, could affect which information one
360 would like to present to the exerciser. Furthermore, not only the opponent’s behavior, but also
361 the interdependency between the athlete and the opponent appeared to be crucial in the decision-
362 making process involved in pacing, highlighting the importance of athlete-environment
363 interactions in the context of pacing. That is, attentional cues are likely to be used in a much
364 more adaptive way in the context of pacing than previously suggested in many of the existing
365 theories about pacing regulation, according to their availability and situational relevance, and
366 consistent with a decision-making framework based on the interdependence of perception and
367 action.

368

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371

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373 No funding was received for the present study. The authors declare no conflicts of interest. The
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375 the results of the study are presented clearly, honestly, and without fabrication, falsification, or
376 inappropriate data manipulation.

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469

470 FIGURE CAPTIONS

471 **Figure 1.** Overview of the projected screen set-up during the time-trial. Projected information
472 included speed, elapsed distance, pedaling cadence, heart rate, gearing, and elapsed time.
473 Furthermore, the video simulation of the time-trial course, the virtual cycling avatar
474 representing the participant itself, and the virtual cycling avatar of the virtual opponent (only in
475 OP-DEP and OP-IND) were projected onto the wall.

476



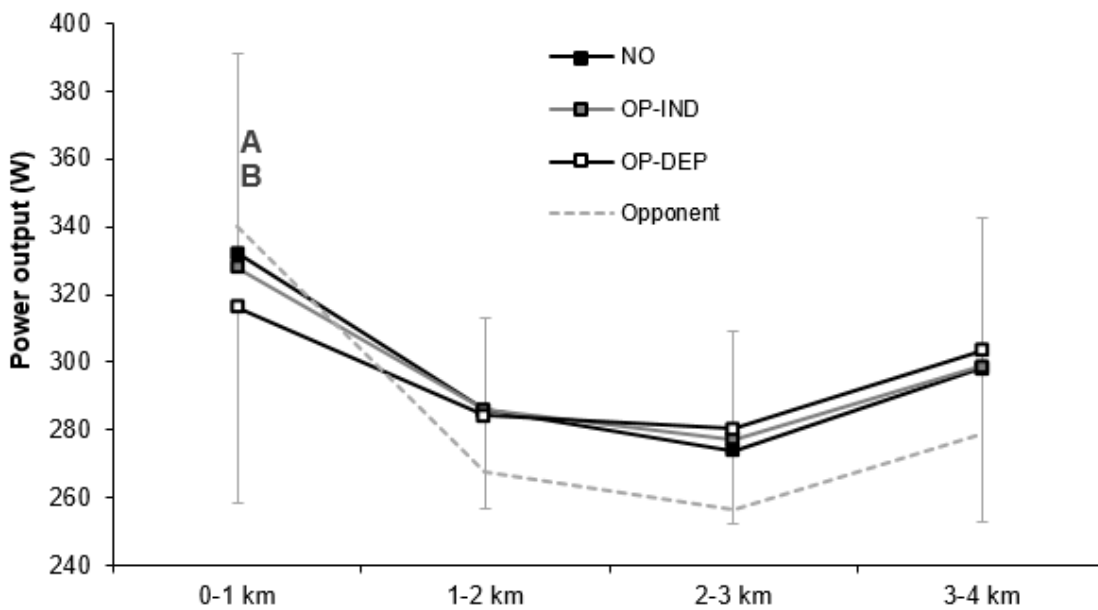
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479 **Figure 2.** Mean (\pm SD) power output per kilometer segment for each experimental condition
480 (NO, OP-IND, and OP-DEP).

481 ^A Difference between NO and OP-DEP ($P < 0.05$); ^B Difference between OP-IND and OP-DEP ($P < 0.05$).

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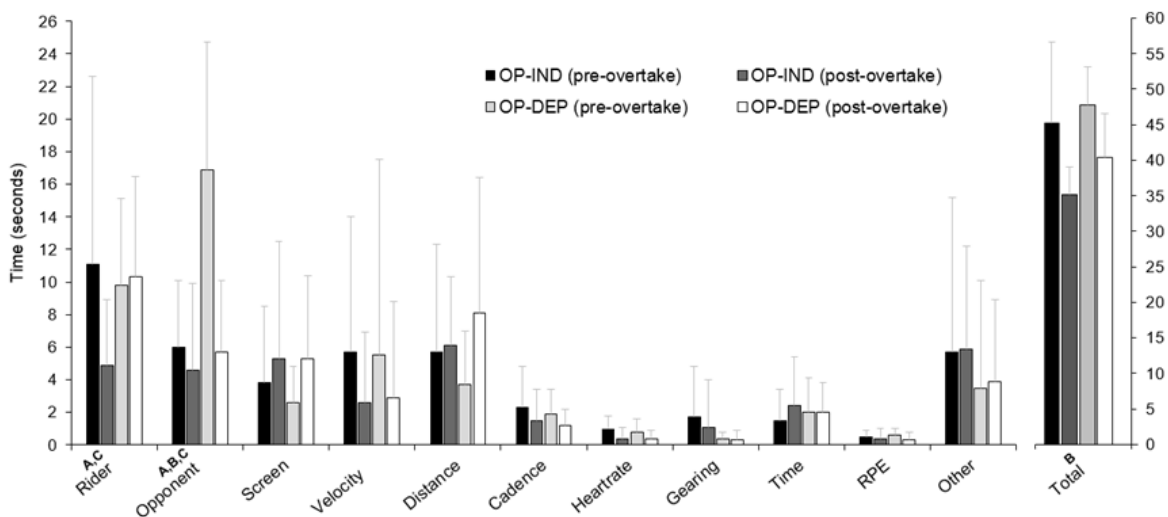


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485 **Figure 3.** Mean \pm SD of the fixation time spent per categorized variables prior and
486 after the overtake took place, corrected for duration of the segment (%).

487 ^A difference between OP-IND and OP-DEP in fixation time spent ($p < 0.05$), ^B difference between pre-overtake
488 and post-overtake in fixation time spent ($p < 0.05$), ^C difference between pre-overtake and post-overtake between
489 OP-IND and OP-DEP in fixation time spent ($p < 0.05$)

490



491 ^A difference between OP-IND and OP-DEP in fixation time spent ($p < 0.05$), ^B difference between pre-overtake and post-overtake in fixation
492 time spent ($p < 0.05$), ^C difference between pre-overtake and post-overtake between OP-IND and OP-DEP in fixation time spent ($p < 0.05$).

Table 1. Mean \pm SD values for the time trial performance variables completion time, power output, heart rate and cadence per experimental condition, and RPE scores of the participant per experimental condition per kilometer, and directly after finishing.

	NO	OP-IND	OP-DEP
Completion Time (sec)	377.7 \pm 17.4	378.9 \pm 19.7	378.5 \pm 17.7
Power Output (W)	297.5 \pm 47.2	296.7 \pm 47.3	296.0 \pm 44.3
Heart Rate (bpm)	162.5 \pm 13.8	162.1 \pm 15.4	161.3 \pm 15.1
Cadence (rpm)	101.3 \pm 12.5	100.5 \pm 10.2	99.7 \pm 8.3
Rating of Perceived Exertion (6-20)			
TT-1 km	13.7 \pm 1.8	14.0 \pm 1.7	13.3 \pm 2.0
TT-2 km	15.8 \pm 1.5	16.2 \pm 1.6	15.5 \pm 1.6
TT-3 km ^{A,B}	17.8 \pm 1.1	17.7 \pm 1.4	16.5 \pm 1.4
TT-Finish	19.5 \pm 0.7	19.2 \pm 0.8	19.0 \pm 0.9

^A Difference between NO and OP-DEP ($P < 0.05$), ^B Difference between OP-IND and OP-DEP ($P < 0.05$).

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Table 2. Mean \pm SD values for the total fixation time spent (in seconds) and number of fixations per categorized variable per experimental condition over the whole trial.

	NO		OP-IND		OP-DEP	
	Fixation time spent	No of fixations	Fixation time spent	No of fixations	Fixation time spent	No of fixations
Rider. ^{A,B,D,E,F}	7.4 \pm 5.3	24 \pm 14	38.6 \pm 12.9	88 \pm 38	37.4 \pm 12.1	123 \pm 48
Opponent. ^{C,F}	NA	NA	23.3 \pm 16.6	65 \pm 30	55.8 \pm 32.7	130 \pm 51
Screen	28.6 \pm 37.7	52 \pm 35	12.6 \pm 16.7	34 \pm 28	11.3 \pm 9.2	39 \pm 23
Velocity. ^{A,B,E}	31.1 \pm 29.8	55 \pm 37	19.7 \pm 21.1	38 \pm 28	15.7 \pm 28.4	31 \pm 35
Distance	32.5 \pm 36.3	69 \pm 34	23.4 \pm 16.1	59 \pm 22	19.1 \pm 13.2	54 \pm 24
Cadence ^B	13.7 \pm 9.8	37 \pm 25	9.1 \pm 8.0	31 \pm 22	6.4 \pm 4.6	25 \pm 13
Heartrate	3.5 \pm 2.8	14 \pm 7	3.1 \pm 2.1	13 \pm 7	2.5 \pm 2.3	10 \pm 7
Gearing	1.3 \pm 1.1	6 \pm 4	1.6 \pm 1.1	6 \pm 5	1.0 \pm 1.9	5 \pm 4
Time	9.8 \pm 7.4	27 \pm 14	8.1 \pm 7.8	21 \pm 14	7.3 \pm 6.0	21 \pm 13
RPE ^E	3.1 \pm 1.6	7 \pm 3	3.2 \pm 3.3	6 \pm 5	2.9 \pm 2.0	4 \pm 2
Other	18.2 \pm 16.8	28 \pm 21	15.6 \pm 18.0	23 \pm 21	15.0 \pm 24.2	21 \pm 27
Total ^{B,C,D,E,F}	149.1 \pm 51.5	318 \pm 94	161.6 \pm 49.4	389 \pm 85	174.6 \pm 42.0	462 \pm 98

^A difference between NO and OP-IND in fixation time spent ($p < 0.05$), ^B difference between NO and OP-DEP in fixation time spent ($p < 0.05$), ^C difference between OP-IND and OP-DEP in fixation time spent ($p < 0.05$), ^D difference between NO and OP-IND in number of fixations ($p < 0.05$), ^E difference between NO and OP-DEP in number of fixations ($p < 0.05$), ^F difference between OP-IND and OP-DEP in number of fixations ($p < 0.05$).

Table 3. The information-seeking behavior during the 10 seconds prior to the overtake of the virtual opponent in OP-DEP (N=10).

OP-DEP - 10 seconds prior to overtake		
	Fixation time spent (in sec)	Number of fixations
Rider.	1.3 \pm 0.9	5 \pm 2
Opponent	1.6 \pm 0.8	5 \pm 2

Screen	0.4 ± 0.4	1 ± 1
Velocity	0.4 ± 0.8	1 ± 2
Distance	0.6 ± 0.7	2 ± 2
Cadence	0.2 ± 0.2	1 ± 1
Heartrate	0.1 ± 0.2	0 ± 0
Gearing	0.0 ± 0.1	0 ± 0
Time	0.3 ± 0.7	0 ± 1
RPE	0.0 ± 0.0	0 ± 0
Other	0.1 ± 0.3	0 ± 1
Total	5.0 ± 1.4	16 ± 3

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