Athlete–Opponent Interdependency Alters Pacing and Information-Seeking Behavior

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ABSTRACT

KONINGS, M. J., T. FOULSHAM, D. MICKLEWRIGHT, and F. J. HETTINGA. Athlete–Opponent Interdependency Alters Pacing and Information-Seeking Behavior. *Med. Sci. Sports Exerc.*, Vol. 52, No. 1, pp. 153–160, 2020. **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 s; OP-IND, 379.3 ± 19.5 s; OP-DEP, 378.5 ± 17.7 s) differed between experimental conditions. However, power output was lower in the first kilometer of OP-DEP compared with 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 s; OP-DEP, 255 ± 107 s; $P = 0.040$). 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 s; OP-DEP, 55.8 ± 32.7 s; $P = 0.002$). **Conclusion:** A higher interdependency between athlete and opponent altered pacing behavior in terms of in-race adaptations based on opponent's behavior, and it 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. **Key Words:** PACING STRATEGY, ATTENTIONAL FOCUS, GAZE ANALYSIS, SPORT PERFORMANCE

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

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

The present study explored the influence of interdependency between competitors on the decision-making process involved in pacing. This has been done by only altering instructions, and thereby action possibilities, while controlling the environment (e.g., competitor behavior) and exercise task.

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

METHODS

Participants. Twelve participants with at least 2 yr of cycling experience with training at a moderate to high intensity (age, 45.8 ± 7.0 yr; body mass, 78.7 ± 10.4 kg; height, 176.6 ± 7.4 cm) participated in this study. All participants were moderately to highly physically active (two or more moderate to high-intensity training sessions per week) and familiar with pacing their exercise. All participants gave prior written informed consent and completed a health screening questionnaire (Physical Activity Readiness Questionnaire [12]). The study was approved by the ethical committee of the University of Essex in accordance with the Declaration of Helsinki.

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

The same opponent was used for both OP-IND and OP-DEP. This opponent was constructed based on the fastest familiarization trial of the participant. To maximize the chances that the opponent would be in front of the participant directly after the start, yet preventing a too big initial gap between participant and opponent, the opponent was set to adopt an initial pace that led to a 1-s lead after 250 m compared with the fastest familiarization trial of the participant. Hereafter, the opponent adopted a pace of 95% of the power output as achieved in the fastest familiarization trial.

Before every time trial, participants were instructed to provide maximal effort. No verbal coaching or motivation was given to the participants during any of the trials. Participants were told that their opponent would be of similar level of performance to simulate a competitive situation where participants perceived their chances of success to be realistic. Time trials were completed at the same time of the day (±2 h) to minimize circadian variation (13,14) and 3–7 d apart to limit training adaptations. Participants were asked to maintain normal activity and sleep pattern throughout the testing period. In addition, participants were asked to refrain from any strenuous exercise and alcohol consumption in the preceding 24 h, and from caffeine and food consumption, respectively, 4 and 2 h before the start of the test. Participants were informed that the study was examining cycling performance during 4-km time trials. To prevent any premeditated influence on preparation or preexercise state, the specific feedback presented for each trial was only revealed immediately before the start of the time trial. All trials were conducted in ambient temperatures between 18°C and 21°C.

Apparatus. Time trials were performed on an advanced cycle ergometer (Velotron Dynafit; Racermate, Seattle, WA), a reliable and valid device for measuring cycling performance and pacing behavior. Using the Velotron 3D software, a flat 4-km time trial course with no wind was programmed and projected onto a large screen in front of the participants for all trials. The cycle ergometer was positioned such that the screen itself was offset to the right of the natural forward field of vision of the cyclists. Offsetting the screen in this way required participants to rotate their neck to look at the projected information, thus adding confidence that the eye-tracking measurements constituted deliberate attempts to acquire information, rather than information glances just because it happened to fall naturally within the participant's forward field of vision. Notwithstanding minor projector repositioning variances, the projected screen size was 2.1 m wide by 1.5 m high, with the bottom border of the projection running 1 m above and parallel to the floor. The cycle ergometer was positioned such that the handlebar stem riser was 3 m perpendicular to the plane of the screen. An A0-sized RPE scale was also displayed to the left of the projector screen clearly visible to the participants while sitting on the cycle ergometer. Before the start of each time trial, participants gave a confirmatory answer when asked if all displayed information was clearly visible for them while sitting on the cycle ergometer. Incorporated into the projection beneath the simulated time trial video were five fields of real-time feedback information that, presented from left to right, were speed ($km \cdot h^{-1}$), elapsed distance (km), pedaling cadence (rpm), heart rate (bpm), and gearing. In addition, elapsed time (min:s) was displayed right above the gearing field (see Fig. 1). Furthermore, in all time trials, a virtual avatar of the participant was projected onto the screen. In OP-IND and

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

OP-DEP, a virtual avatar of an opponent was projected onto the screen as well. The virtual opponent was in this case always visible on the left side of the road, whereas the virtual avatar of the participant itself was projected onto the right side of the road. This was also clearly communicated to the participants before the time trial. The course was projected in helicopter view (see Fig. 1) to ensure both virtual avatars were visible to the participant throughout the whole trial, regardless whether the participant was riding in front or behind. Angular separation of the information fields was well beyond the manufacturer-defined eye-tracker spatial resolution of 0.1° and gaze position accuracy within the nearest degree. The separation of the projected information blocks, therefore, facilitated clear differentiation in eye-tracker measurements.

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

Information-seeking behavior. All participants wore a glasses-based mobile binocular eye-tracking device (SensoMotoric Instruments SMI eye-tracking glasses; Sensomotoric Instruments, Tetlow, Germany) during the experimental time trial conditions to capture their eye movements during the time trial. The system tracks eye movements using pupil and corneal reflex so that each participant's point of regard can be superimposed onto the recorded scene, thus enabling timed measurements to be made of eye fixations. The SMI eye-tracking glasses were calibrated using a three-point calibration before starting to record. Eye position was recorded at 60 Hz, which was then down-sampled to 30 frames per second for the resulting scene videos.

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

Directly after finishing OP-DEP, a retrospective think aloud protocol was used to gather qualitative information on the participants intents and reasoning around the overtake of the virtual competitor. This involved the 30 s before and the 30 s after the overtake. A video replay of the projected screen in this minute was shown to the participant as a visual reminding stimulus, and participants were instructed to recall as much information as possible from this period.

Data analysis. Mean power output, cadence, heart rate, and finish time were determined to examine performance.

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TABLE 1. Mean ± 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 (s)	377.7 ± 17.4	378.9 ± 19.7	378.5 ± 17.7
Power output (W)	297.5 ± 47.2	296.7 ± 47.3	296.0 ± 44.3
Heart rate (bpm)	162.5 ± 13.8	162.1 ± 15.4	161.3 ± 15.1
Cadence (rpm)	101.3 ± 12.5	100.5 ± 10.2	99.7 ± 8.3
RPE (6–20)			
TT-1 km	13.7 ± 1.8	14.0 ± 1.7	13.3 ± 2.0
TT-2 km	15.8 ± 1.5	16.2 ± 1.6	15.5 ± 1.6
TT-3 km[a,b]	17.8 ± 1.1	17.7 ± 1.4	16.5 ± 1.4
TT-Finish	19.5 ± 0.7	19.2 ± 0.8	19.0 ± 0.9

[a]Difference between NO and OP-DEP ($P < 0.05$).
[b]Difference between OP-IND and OP-DEP ($P < 0.05$).

Differences in performance between conditions were assessed using a repeated-measures ANOVA. To assess differences in pacing behavior between the conditions, average power output, cadence, heart rate, and split times for each 1-km segment were calculated, and differences were tested using a two-way repeated-measures ANOVA (condition–segment). *Post hoc* tests with Bonferroni correction were performed when significant results were found. Information-seeking behavior was assessed using the total fixation time and the total number of fixations for each object of interest over the whole time trial and per kilometer. Differences in information-seeking behavior were tested using a two-way repeated-measures ANOVA (condition–segment). All analyses were performed using SPSS 19.0, and significance was accepted at $P < 0.05$.

RESULTS

Performance analysis. Mean ± SD finishing time, power output, heart rate, and cadence for the three experimental time trial conditions are shown in Table 1. No main effects were found for finishing time ($F = 0.428$, $P = 0.569$), power output ($F = 0.384$, $P = 0.605$), heart rate ($F = 0.389$, $P = 0.682$), or cadence ($F = 0.509$, $P = 0.608$).

Pacing analysis. Mean power outputs per kilometer are shown in Figure 2. A main effect for segment ($F = 8.3$, $P = 0.003$), but not for condition ($F = 0.4$, $P = 0.605$), was found. An interaction effect for condition–segment ($F = 2.3$, $P = 0.042$) was revealed, indicating differences in pacing profile between conditions. *Post hoc* analysis revealed a higher power output during the first kilometer in NO compared with OP-DEP ($P = 0.015$) and a higher power output during the first kilometer in OP-IND compared with OP-DEP ($P = 0.042$). No differences in pacing were shown between NO and OP-IND. During OP-IND, the power output of the participants in the initial 250 m was on average 9.8% above the mean power output of the trial. During OP-DEP, this was on average 5.6%.

A main effect of segment on heart rate ($F = 196.1$, $P < 0.001$), but neither a main effect for condition ($F = 0.4$, $P = 0.682$) nor an interaction effect condition–segment ($F = 0.7$, $P = 0.521$), was observed. No main effect for cadence for condition ($F = 0.5$, $P = 0.608$) or segment ($F = 1.8$, $P = 0.195$) and no interaction effect for condition–segment ($F = 1.0$, $P = 0.397$) were found.

Mean RPE scores per kilometer for each experimental condition are shown in Table 1. A main effect for segment ($F = 297.1$, $P < 0.001$) was reported, but no main effect for condition ($F = 0.8$, $P = 0.448$) was found. In addition, an interaction effect for condition–segment ($F = 2.2$, $P = 0.038$) was revealed. *Post hoc* analysis indicated a higher RPE score after 3 km in NO compared with OP-DEP ($P = 0.003$), and a higher RPE score after 3 km in OP-IND compared with OP-DEP ($P = 0.023$). No differences in RPE were found between NO and OP-IND.

Information-seeking analyses. The mean fixation time spent and the number of fixations in total and per categorized variable per experimental condition over the whole trial are shown in Table 2. Analysis revealed a main effect of condition on the mean fixation time spent on the rider ($F = 9.8$, $P = 0.005$) and the opponent ($F = 15.5$, $P = 0.002$), as well

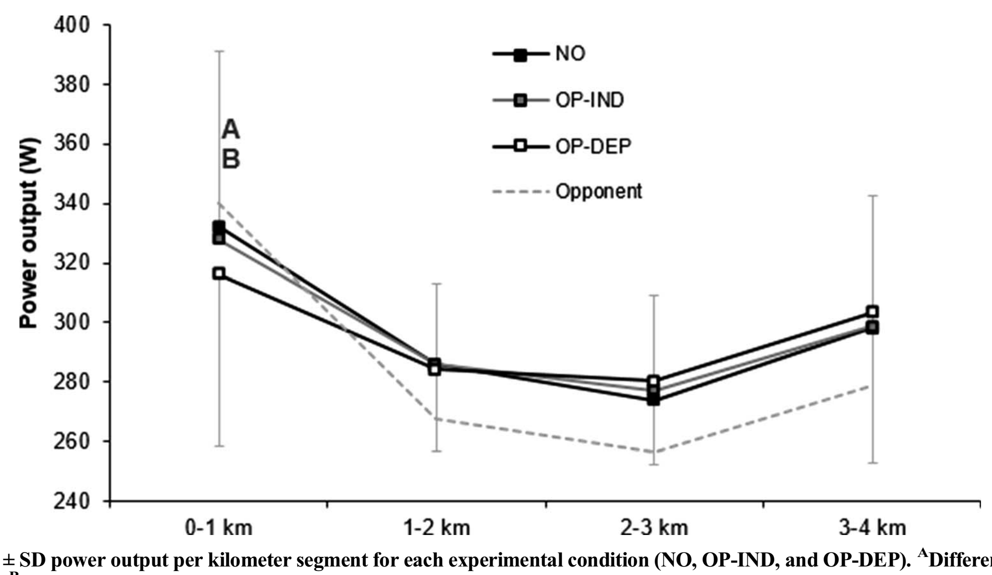

FIGURE 2—Mean ± SD power output per kilometer segment for each experimental condition (NO, OP-IND, and OP-DEP). [A]Difference between NO and OP-DEP ($P < 0.05$). [B]Difference between OP-IND and OP-DEP ($P < 0.05$).

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TABLE 2. Mean ± SD values for the total fixation time spent (s) and number of fixations per categorized variable per experimental condition over the whole trial.

	NO		OP-IND		OP-DEP	
	Fixation Time Spent	No. Fixations	Fixation Time Spent	No. Fixations	Fixation Time Spent	No. Fixations
Rider[a,b,d,e,f]	7.4 ± 5.3	24 ± 14	38.6 ± 12.9	88 ± 38	37.4 ± 12.1	123 ± 48
Opponent[c,f]	NA	NA	23.3 ± 16.6	65 ± 30	55.8 ± 32.7	130 ± 51
Screen	28.6 ± 37.7	52 ± 35	12.6 ± 16.7	34 ± 28	11.3 ± 9.2	39 ± 25
Velocity[a,b,e]	31.1 ± 29.8	55 ± 37	19.7 ± 21.1	38 ± 28	15.7 ± 28.4	31 ± 35
Distance	32.5 ± 36.3	69 ± 34	23.4 ± 16.1	59 ± 22	19.1 ± 13.2	54 ± 24
Cadence[b]	13.7 ± 9.8	37 ± 25	9.1 ± 8.0	31 ± 22	6.4 ± 4.6	25 ± 13
Heartrate	3.5 ± 2.8	14 ± 7	3.1 ± 2.1	13 ± 7	2.5 ± 2.3	10 ± 7
Gearing	1.3 ± 1.1	6 ± 4	1.6 ± 1.1	6 ± 5	1.0 ± 1.9	5 ± 4
Time	9.8 ± 7.4	27 ± 14	8.1 ± 7.8	21 ± 14	7.3 ± 6.0	21 ± 13
RPE[e]	3.1 ± 1.6	7 ± 3	3.2 ± 3.3	6 ± 5	2.9 ± 2.0	4 ± 2
Other	18.2 ± 16.8	28 ± 21	15.6 ± 18.0	23 ± 21	15.0 ± 24.2	21 ± 27
Total[b,c,d,e,f]	149.1 ± 51.5	318 ± 94	161.6 ± 49.4	389 ± 85	174.6 ± 42.0	462 ± 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 ($P < 0.05$).

as on information about velocity ($F = 5.7$, $P = 0.010$), cadence ($F = 5.2$, $P = 0.014$), and total ($F = 5.7$, $P = 0.010$). *Post hoc* analysis revealed an increased focus on the avatar of the rider during OP-IND compared with NO ($P = 0.013$) and during OP-DEP compared with NO ($P < 0.001$), but no difference between OP-DEP and OP-IND ($P = 0.870$). Time fixating on the virtual opponent was much higher in OP-DEP compared with OP-IND ($P = 0.002$). Participants showed a decreased focus on the velocity feedback during OP-IND compared with NO ($P = 0.028$) and during OP-DEP compared with NO ($P = 0.014$). A decreased amount of time was spent fixating on the cadence feedback in OP-DEP compared with NO ($P = 0.007$). Finally, when taking all variables together, total fixation time spent over the whole trial was higher in OP-DEP compared with NO ($P = 0.008$) and in OP-DEP compared with OP-IND ($P = 0.031$). No effect for condition was reported for any of the other categories.

A main effect for segment was revealed for rider ($F = 4.4$, $P = 0.024$), opponent ($F = 23.1$, $P < 0.001$), velocity ($F = 6.5$, $P = 0.023$), cadence ($F = 3.7$, $P = 0.021$), gearing ($F = 6.4$, $P = 0.014$), RPE ($F = 12.0$, $P < 0.001$), other ($F = 4.5$, $P = 0.034$), and total ($F = 21.8$, $P < 0.001$). *Post hoc* analysis revealed a decline in the time spent fixating on all these variables over the race, except other and RPE. Time spent fixating on other increased per kilometer, whereas time spent fixating on RPE is higher from the first until the third kilometer, likely related to the moment of asking RPE after each kilometer. No effect for segment was found for any of the other categories.

An interactive effect for condition–segment was revealed for opponent ($F = 6.0$, $P = 0.002$) and screen ($F = 4.7$, $P < 0.001$). Yet, participants still spent more time fixating on the opponent in every kilometer during OP-DEP compared with OP-IND (all $P < 0.05$; e.g., first kilometer, OP-IND = 7.8 ± 3.9 and OP-DEP = 17.4 ± 8.4 s; fourth kilometer, OP-IND = 3.7 ± 3.9 s and OP-DEP = 7.7 ± 6.9 s). In addition, the number of fixations on opponent showed a steady decline per kilometer during OP-IND, whereas in OP-DEP, there is only a decline in the number of fixations in the fourth kilometer compared with the third kilometer. Finally, participants spent less time fixating on the screen (excluding avatars) in the first 2 km of OP-DEP compared with NO ($P = 0.041$ and $P = 0.024$, respectively). No interaction effect was found for any of the other categories.

Overtaking analysis and outcomes talk aloud procedure. A total of 9 out of 12 participants were able to overtake their opponent in both OP-IND and in OP-DEP, whereas 2 participants only overtook their opponent in OP-IND and 1 participant only overtook his opponent in OP-DEP. In this sense, all participants proved to be able to overtake (and beat) their opponent at least once. The average number of overtakes was 0.9 ± 0.3 in OP-IND and 0.8 ± 0.4 in OP-DEP ($P = 0.586$). Participants decided to wait longer before they first overtook their opponent in OP-DEP (overtake at 67% ± 28% of race completion) compared with OP-IND (overtake at 36% ± 34% of race completion; $P = 0.040$). The mean fixation time spent per categorized variables before and after the overtake took place, normalized for duration in percentages, can be found in Figure 3. The information-seeking behavior during the 10 s before the overtake of the virtual opponent in OP-DEP can be found in Table 3.

The retrospective talk aloud procedure revealed that velocity, (remaining) distance, and the virtual opponent were the most important cues of information for participants regarding the overtaking decision. In this respect, 9 out of 10 participants who overtook their virtual opponent in OP-DEP mentioned that they decided to overtake their opponent when they perceived themselves capable of covering the remaining distance without significant deceleration.

DISCUSSION

The present study examined how a difference in the interdependency between the athlete and the opponent would affect exercise regulation and information-seeking behavior. It seemed that cyclists adopted a slower initial pace and decided to wait longer before overtaking their opponent when they

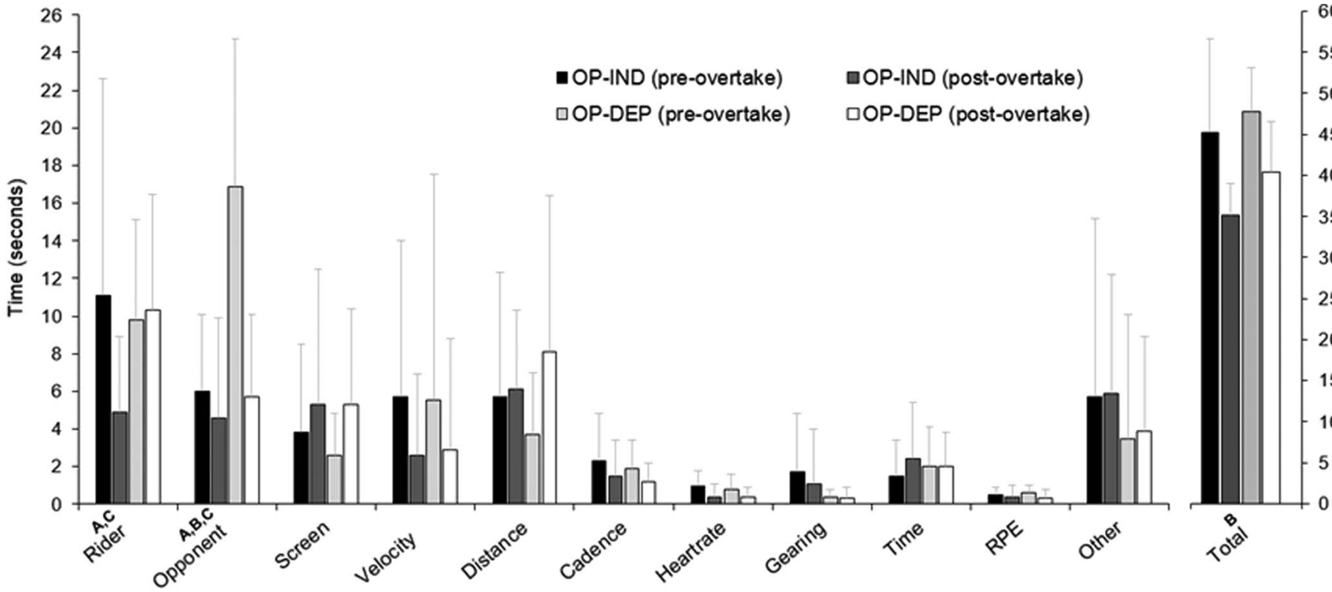

FIGURE 3—Mean ± SD of the fixation time spent per categorized variables before and after the overtake took place, corrected for duration of the segment (%). [A]Difference between OP-IND and OP-DEP in fixation time spent ($P < 0.05$). [B]Difference between preovertake and postovertake in fixation time spent ($P < 0.05$). [C]Difference between preovertake and postovertake between OP-IND and OP-DEP in fixation time spent ($P < 0.05$).

became more dependent on their competitor. Furthermore, a difference in information-seeking behavior was revealed. That is, participants were looking for different information in OP-DEP, mainly due to an increased focus on the avatars of themselves and their opponents, while focusing less on their velocity and cadence feedback.

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

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

The presence of a virtual competitor led to an increased focus on the avatar of the participant itself and a decreased attentional focus on the velocity feedback. By contrast, the manipulation of the interdependency between athlete and opponent mainly affected the attentional focus on the virtual opponent. That is, when participants became more dependent on their opponent, the total fixation time at this virtual opponent increased drastically. This finding highlights the importance of perception in relation to action possibilities, whereas the environment and athlete did not differ between OP-DEP and OP-IND. In addition, an increase in the number of

TABLE 3. The information-seeking behavior during the 10 s before the overtake of the virtual opponent in OP-DEP ($N = 10$).

	OP-DEP—10 s before Overtake	
	Fixation Time Spent (s)	Number of Fixations
Rider	1.3 ± 0.9	5 ± 2
Opponent	1.6 ± 0.8	5 ± 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

fixations, but not in total fixation time spent, on the avatar of the participant itself is noted in the high interdependency condition (OP-DEP), suggesting many glances rather than fewer and longer fixations. This is likely an indication of frequent monitoring of the distance between the avatar of the participant and the avatar of the opponent during the time trial. In addition, time spent fixating on the avatar of the opponent decreased after the overtake compared with before in OP-DEP, but not in OP-IND.

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

In addition to alterations in information-seeking behavior, manipulation of the interdependency between competitors also altered the pacing behavior of the participants. Comparable effects are likely be seen in observational studies looking into pacing strategies during real-life competitions (2). For example, the pacing strategies of athletes are similar to the optimal pacing strategies as predicted in modeling studies when the performance of the individual athlete is relatively independent of the other competitors, such as in time trial sports (22,23), or sports in which individuals compete in separate lanes (24–27). By contrast, exercisers tend to adjust their pacing behavior based on their competitors when competing in the same lane (9,10,28–31). This effect becomes even more apparent when the interdependency between competitors is further increased, for example, via the aerodynamic beneficial effect of drafting behind an opponent (e.g., in cycling/speed skating [9,29]), or during important events such as the Olympic Games (32). In this perspective, our findings support the hypothesis that the interdependency between competitors could be a crucial promotor for these differences in chosen pacing behavior between different competitive sports. Nevertheless, more research is still needed in this respect in regard to the generalizability of our findings to different ages, levels of fitness, and levels or experience.

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

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

CONCLUSION

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

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