Northumbria Research Link

Journal of Sports Sciences

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

--Manuscript Draft--

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

	Done Page 10, Line 264-266: Check grammar. Done

Figure

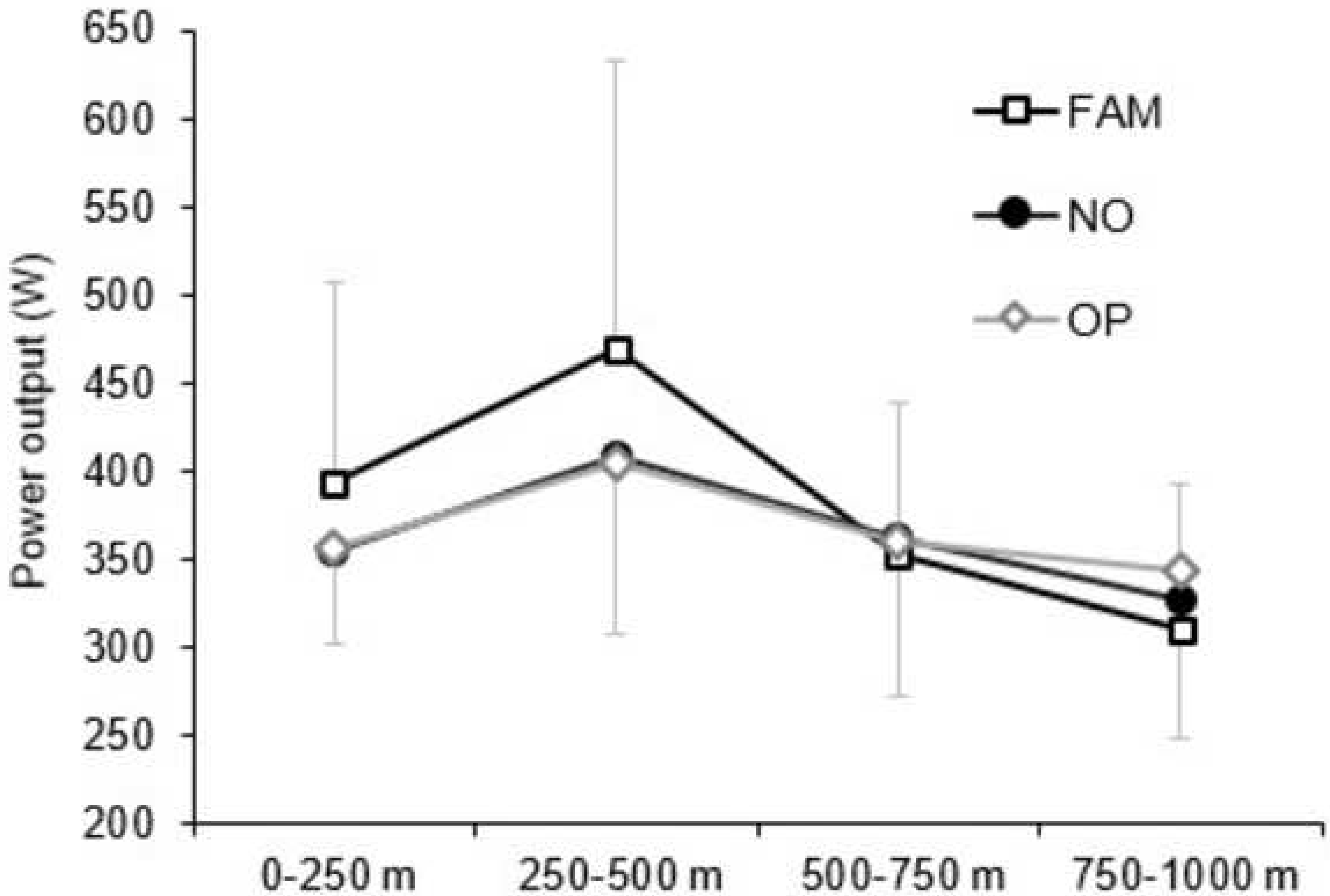

Figure 1. Mean (±SD) power output per 250 m segment per experimental condition.

Figure

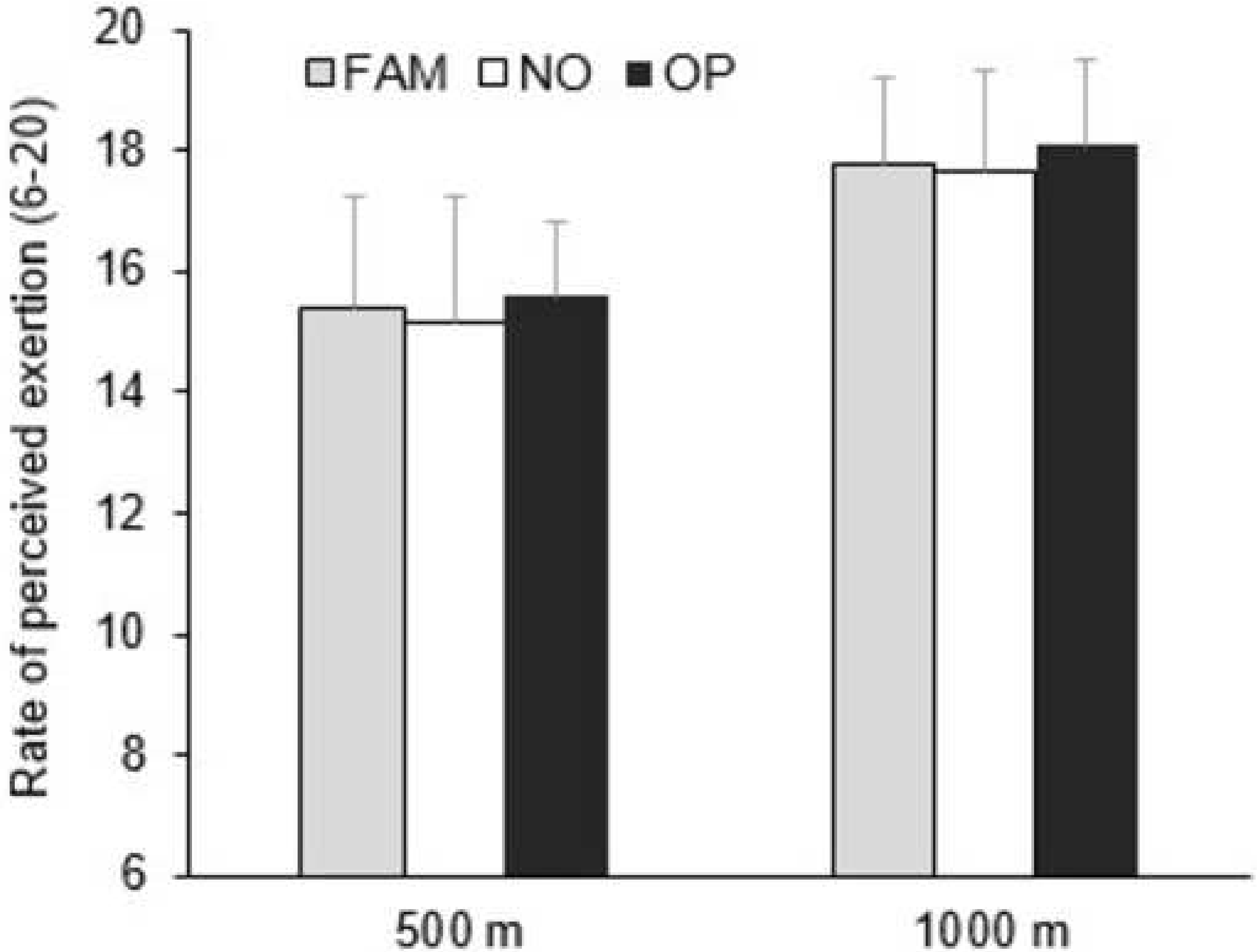

Figure 2. Mean (±SD) RPE scores per experimental condition after 500 m into the time trial and directly after finishing the time trial.

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

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

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

Introduction

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

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

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

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

Although the improvement in time trial performance in the presence of a virtual opponent is a consistent finding, all previous studies have examined the impact of a competitor in time trials with a duration of two minutes or longer. This is of importance, as modelling studies clearly show that optimal pacing strategies in short duration events differ compared with events of more prolonged duration (De Koning, Bobbert, & Foster, 1999; De Koning et al., 2011; Foster et al., 2003; Foster, Hoyos, Earnest, & Lucía, 2005; Hettinga, De Koning, Hulleman, & Foster, 2012). In short distance events (< 2 minutes), creatine phosphate depletion is argued to be the main limiting factor, while in longer events (> 2 minutes) rate of substrate depletion, oxygen consumption, heat accumulation and/or accumulation of fatigue-related metabolites (i.e. inorganic phosphate, potassium and hydrogen ions) are argued to be the main limiting factors (Abbiss & Laursen, 2008; Foster, Hoyos, Earnest, & Lucia, 2005; Tucker, 2009). Consequently, it makes sense that different pacing strategies would fit different distances. Pacing in long distance events is characterized by a high power output in the beginning and the end of a race, with a constant power output in between (Foster et al., 2004, 2003). In contrast, to achieve optimal performance in short distance events it has been advised to adopt a fast starting strategy, with a progressive decrease in power output (De Koning et al., 1999; De Koning, De Groot, & Van Ingen Schenau, 1992; Foster et al., 2004). In this respect, pacing strategies in 250 m, 500 m, and 1 km cycling trials have shown to be different, and even in a 250 m trial peak power is still lower than the potential maximal power output, highlighting the importance of pacing in short time trial events (de Jong et al., 2015). Where these distance-related differences in optimal pacing have been established, it is yet unknown if the presence of competitors impacts differently on pacing and performance in the shorter competitive time trials compared with the more well-researched middle-distance time trials.

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

Materials and methods

Participants

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

Experimental procedures

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

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

Time trials were performed on an advanced cycle ergometer (Velotron Dynafit, Racermate, Seattle, USA). This has proven to be a reliable tool in measuring cycling performance (Astorino & Cottrell, 2012). Using the Velotron 3D software, a straight, flat, 1 km course was configured and projected onto a screen in front of the participant showing the course, plus feedback regarding selected gear and distance travelled. In all time-trials a virtual avatar of the participant on the course was projected onto the screen. In the opponent condition (OP), a second virtual avatar representing the opponent was projected onto the screen as well. All participants began each time trial at the same gear (52/19) and were allowed to change gears as they saw fit during the trial. Prior to the first TT, participants found a suitable seat and handle bar height that was recorded and set for them during each of their trials. Before each 1 km cycling TT, participants were instructed to complete the 1 km distance as fast as they could. In addition, prior to OP participants were also told that the opponent was of similar capabilities to encourage the perception of possible competition. No further verbal instruction or support was given once the trial began. To prevent any pre-meditated influence on preparation or pre-exercise state, the specific instructions and feedback presented for each trial were only revealed immediately before the start of the time trial.

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

Statistical analyses

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

Results

Mean power output, finishing times and cadence per experimental condition can be found in Table 1. In addition, the mean estimated finishing times of the participants directly after time trial completion, and mean absolute error of this estimated finishing times versus actual finishing times are displayed in Table 1. The repeated measures ANOVA revealed no main effects for power output ($F = 0.588$; $p = 0.564$; $d = 0.14$), finishing time ($F = 0.098$; $p = 0.907$, $d = 0.08$), or cadence ($F = 1.973$; $p = 0.183$; $d = 0.14$).

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

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

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

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

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

Discussion

The aim of the present study was to discover whether the influence of an opponent would alter the pacing behaviour and overall performance over a 1 km cycling time trial. It was proposed that the presence of an opponent would invite a change in pacing and evoke an improvement in performance, in line with research in time-trials of more prolonged duration (Hettinga et al., 2017). However, the results revealed that neither overall performance nor pacing behaviour were altered in the presence of an opponent in 1 km cycling time trials. Therefore, our findings suggest that the duration of the time trial may affect the influence of an opponent on pacing behaviour and performance.

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

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

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

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

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

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

Declaration of interest

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

References

Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Medicine*, *38*(3), 239–252.

Astorino, T. A., & Cottrell, T. (2012). Reliability and validity of the velotron racermate cycle ergometer to measure anaerobic power. *International Journal of Sports Physiology and Performance*, *33*(3), 205–210.

Cardinal, B. J., Esters, J., & Cardinal, M. K. (1996). Evaluation of the revised physical activity readiness questionnaire in older adults. *Medicine and Science in Sports and Exercise*, *28*(4), 468–472.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences.* New York, NY, USA: Routledge Academic.

Corbett, J., Barwood, M. J., Ouzounoglou, A., Thelwell, R., & Dicks, M. (2012). Influence of competition on performance and pacing during cycling exercise. *Medicine and Science in Sports and Exercise*, *44*(3), 509–515.

Corbett, J., White, D. K., Barwood, M. J., Wagstaff, C. R., Tipton, M. J., McMorris, T., & Costello, J. T. (2018). The Effect of Head-to-Head Competition on Behavioural Thermoregulation, Thermophysiological Strain and Performance During Exercise in the Heat. *Sports Medicine*, *48*(5), 1269–1279. https://doi.org/10.1007/s40279-017-0816-x

de Jong, J., van der Meijden, L., Hamby, S., Suckow, S., Dodge, C., de Koning, J. J., & Foster, C. (2015). Pacing Strategy in Short Cycling Time Trials. *International Journal of Sports Physiology and Performance*, *10*(8), 1015–1022. https://doi.org/10.1123/ijspp.2014-009

De Koning, J. J., Bobbert, M. F., & Foster, C. (1999). Determination of optimal pacing strategy in track cycling with an energy flow model. *Journal of Science and Medicine in Sport*, *2*(3), 266–277.

De Koning, J. J., De Groot, G., & Van Ingen Schenau, G. J. (1992). A power equation for the sprint in speed skating. *Journal of Biomechanics*, *25*(6), 573–580.

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

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

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

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

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

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

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

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

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

Hettinga, F. J., Konings, M. J., & Pepping, G.-J. (2017). The science of racing against opponents: Affordance competition and the regulation of exercise intensity in head-to-head competition. *Frontiers in Physiology*, *8*, 118. https://doi.org/10.3389/fphys.2017.00118

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Tables

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

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

[1] estimated finishing time only asked after NO and OP

Figure captions

Figure 1. Mean (±SD) power output per 250 m segment per experimental condition.

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

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

Tiffany Wood, Connor Thien Long Bui, Connor Lubbock, Jason Wilson, Scott Jeffrey, Mitchell Lawrence, Colleen Leung, Darshit Mashar, Nicholas Sims, Marco J. Konings, Florentina J. Hettinga

Department of Sport, Exercise & Rehabilitation, Northumbria University, Newcastle Upon Tyne, United Kingdom.

Corresponding Author:

Prof Dr Florentina J Hettinga PhD *SFHEA FECSS FACSM*

Department of Sport, Exercise & Rehabilitation

Faculty of Health and Life Sciences

Northumbria University

Room 238, Northumberland Building

Newcastle Upon Tyne

NE1 8ST

United Kingdom

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

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

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

Introduction

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

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

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

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

Although the improvement in time trial performance in the presence of a virtual opponent is a consistent finding, all previous studies have examined the impact of a competitor in time trials with a duration of two minutes or longer. This is of importance, as modelling studies clearly show that optimal pacing strategies in short duration events differ compared with events of more prolonged duration (De Koning, Bobbert, & Foster, 1999; De Koning et al., 2011; Foster et al., 2003; Foster, Hoyos, Earnest, & Lucía, 2005; Hettinga, De Koning, Hulleman, & Foster, 2012). In short distance events (< 2 minutes), creatine phosphate depletion is argued to be the main limiting factor, while in longer events (> 2 minutes) rate of substrate depletion, oxygen consumption, heat accumulation and/or accumulation of fatigue-related metabolites (i.e. inorganic phosphate, potassium and hydrogen ions) are argued to be the main limiting factors (Abbiss & Laursen, 2008; Foster, Hoyos, Earnest, & Lucia, 2005; Tucker, 2009). Consequently, it makes sense that different pacing strategies would fit different distances. Pacing in long distance events is characterized by a high power output in the beginning and the end of a race, with a constant power output in between (Foster et al., 2004, 2003). In contrast, to achieve optimal performance in short distance events it has been advised to adopt a fast starting strategy, with a progressive decrease in power output (De Koning et al., 1999; De Koning, De Groot, & Van Ingen Schenau, 1992; Foster et al., 2004). In this respect, pacing strategies in 250 m, 500 m, and 1 km cycling trials have shown to be different, and even in a 250 m trial peak power is still lower than the potential maximal power output, highlighting the importance of pacing in short time trial events (de Jong et al., 2015). Where these distance-related differences in optimal pacing have been established, it is yet unknown if the presence of competitors impacts differently on pacing and performance in the shorter competitive time trials compared with the more well-researched middle-distance time trials.

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

Materials and methods

Participants

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

Experimental procedures

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

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

Time trials were performed on an advanced cycle ergometer (Velotron Dynafit, Racermate, Seattle, USA). This has proven to be a reliable tool in measuring cycling performance (Astorino & Cottrell, 2012). Using the Velotron 3D software, a straight, flat, 1 km course was configured and projected onto a screen in front of the participant showing the course, plus feedback regarding selected gear and distance travelled. In all time-trials a virtual avatar of the participant on the course was projected onto the screen. In the opponent condition (OP), a second virtual avatar representing the opponent was projected onto the screen as well. All participants began each time trial at the same gear (52/19) and were allowed to change gears as they saw fit during the trial. Prior to the first TT, participants found a suitable seat and handle bar height that was recorded and set for them during each of their trials. Before each 1 km cycling TT, participants were instructed to complete the 1 km distance as fast as they could. In addition, prior to OP participants were also told that the opponent was of similar capabilities to encourage the perception of possible competition. No further verbal instruction or support was given once the trial began. To prevent any pre-meditated influence on preparation or pre-exercise state, the specific instructions and feedback presented for each trial were only revealed immediately before the start of the time trial.

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

Statistical analyses

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

Results

Mean power output, finishing times and cadence per experimental condition can be found in Table 1. In addition, the mean estimated finishing times of the participants directly after time trial completion, and mean absolute error of this estimated finishing times versus actual finishing times are displayed in Table 1. The repeated measures ANOVA revealed no main effects for power output (F = 0.588; p = 0.564; d = 0.14), finishing time (F = 0.098; p = 0.907, d = 0.08), or cadence (F = 1.973; p = 0.183; d = 0.14).

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

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

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

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

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

Discussion

The aim of the present study was to discover whether the influence of an opponent would alter the pacing behaviour and overall performance over a 1 km cycling time trial. It was proposed that the presence of an opponent would invite a change in pacing and evoke an improvement in performance, in line with research in time-trials of more prolonged duration (Hettinga et al., 2017). However, the results revealed that neither overall performance nor pacing behaviour were altered in the presence of an opponent in 1 km cycling time trials. Therefore, our findings suggest that the duration of the time trial may affect the influence of an opponent on pacing behaviour and performance.

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

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

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

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

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

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

Acknowledgments

The authors would like to thank Gavin Sandercock for his contributions to the development of this study.

Declaration of interest

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

References

Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Medicine*, *38*(3), 239–252.

Astorino, T. A., & Cottrell, T. (2012). Reliability and validity of the velotron racermate cycle ergometer to measure anaerobic power. *International Journal of Sports Physiology and Performance*, *33*(3), 205–210.

Cardinal, B. J., Esters, J., & Cardinal, M. K. (1996). Evaluation of the revised physical activity readiness questionnaire in older adults. *Medicine and Science in Sports and Exercise*, *28*(4), 468–472.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences.* New York, NY, USA: Routledge Academic.

Corbett, J., Barwood, M. J., Ouzounoglou, A., Thelwell, R., & Dicks, M. (2012). Influence of competition on performance and pacing during cycling exercise. *Medicine and Science in Sports and Exercise*, *44*(3), 509–515.

Corbett, J., White, D. K., Barwood, M. J., Wagstaff, C. R., Tipton, M. J., McMorris, T., & Costello, J. T. (2018). The Effect of Head-to-Head Competition on Behavioural Thermoregulation, Thermophysiological Strain and Performance During Exercise in the Heat. *Sports Medicine*, *48*(5), 1269–1279. https://doi.org/10.1007/s40279-017-0816-x

de Jong, J., van der Meijden, L., Hamby, S., Suckow, S., Dodge, C., de Koning, J. J., & Foster, C. (2015). Pacing Strategy in Short Cycling Time Trials. *International Journal of Sports Physiology and Performance*, *10*(8), 1015–1022. https://doi.org/10.1123/ijspp.2014-009

De Koning, J. J., Bobbert, M. F., & Foster, C. (1999). Determination of optimal pacing strategy in track cycling with an energy flow model. *Journal of Science and Medicine in Sport*, *2*(3), 266–277.

De Koning, J. J., De Groot, G., & Van Ingen Schenau, G. J. (1992). A power equation for the sprint in speed skating. *Journal of Biomechanics*, *25*(6), 573–580.

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

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

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

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

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

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

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

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

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

Hettinga, F. J., Konings, M. J., & Pepping, G.-J. (2017). The science of racing against opponents: Affordance competition and the regulation of exercise intensity in head-to-head competition. *Frontiers in Physiology*, *8*, 118. https://doi.org/10.3389/fphys.2017.00118

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Tables

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

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

[1] estimated finishing time only asked after NO and OP

Figure captions

Figure 1. Mean (±SD) power output per 250 m segment per experimental condition.

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