

Influence of Competition on Performance and Pacing during Cycling Exercise

JO CORBETT¹, MARTIN J. BARWOOD¹, ALEX OUZOUNOGLU¹, RICHARD THELWELL¹, and MATTHEW DICKS²

¹University of Portsmouth, Portsmouth, UNITED KINGDOM; and ²Deutsche Sporthochschule (German Sport University), Cologne, GERMANY

ABSTRACT

CORBETT, J., M. J. BARWOOD, A. OUZOUNOGLU, R. THELWELL, and M. DICKS. Influence of Competition on Performance and Pacing during Cycling Exercise. *Med. Sci. Sports Exerc.*, Vol. 44, No. 3, pp. 509–515, 2012. **Purpose:** The study's purpose was to examine the influence of head-to-head (HH) competition on performance, pacing strategy, and bioenergetics during a 2000-m cycling task. **Methods:** Fourteen participants completed three 2000-m familiarization time trials (TTs) on a Velotron cycle ergometer, before completing an additional TT and a 2000-m simulated HH competition in a counterbalanced order. During the trials, a computer-generated image of the participants completing the 2000-m course was projected onto a screen positioned in front of the participants. Although participants believed they were competing against another individual during the HH competition, they were in fact competing against their best familiarization performance (FAM), replayed on the screen by the Velotron software. **Results:** Performance was significantly faster in HH than in FAM or TT (184.6 ± 6.2 , 187.7 ± 8.2 , and 188.3 ± 9.5 s, respectively). Pacing profile in HH initially matched the FAM performance but was better maintained from 1000 m until the end of exercise. The higher power output during the latter part of the test was achieved by a greater anaerobic energy contribution, whereas the aerobic energy yield remained unchanged. **Conclusions:** HH competition encourages participants to increase their performance. This occurs primarily via an increased anaerobic energy yield, which seems to be centrally mediated, and is consistent with the concept of a physiologic reserve. **Key Words:** BIOENERGETICS, FATIGUE, ANAEROBIC CAPACITY, SOCIAL FACILITATION

It has long been known that athletes will frequently perform better when competing against other athletes than when exercising alone (26). The basis for this improvement has often been interpreted about psychological constructs such as the social facilitation theory (2), drive theory (29), or motivational intensity theory (7). However, the bioenergetic basis for such performance improvements is typically unexplained. An early study by Wilmore (28) demonstrated an increased time to exhaustion during incremental exercise when athletes competed against another athlete of similar ability than when they exercised alone. Because maximum oxygen uptake remained unchanged, the improved performance was attributed to an increased energy yield from anaerobic sources. However, the validity of this type of exercise model has recently been criticized because humans

seldom exercise in a manner in which work rate is externally controlled and progressively increased (18).

The performance of athletes undertaking self-paced exercise alone can be remarkably robust. For instance, Foster et al. (10) reported mean times of 133.8 ± 6.6 , 133.9 ± 5.8 , and 133.8 ± 5.5 s for a series of solo 1500-m cycle time trials (TTs) separated by 48 h of recovery. A subsequent study using the same exercise model demonstrated that performance was not significantly influenced by the offer of a monetary incentive, paid if participants were able to beat their previous best time by >1 s (14). Similarly, Corbett et al. (9) have reported mean times of 191.4 ± 4.3 , 189.4 ± 4.6 , and 190.1 ± 5.6 s for naive participants in a series of 2000-m cycling TTs, with a coefficient of variation (CV) of 1.1% between test 1 and test 2 and of 0.9% between test 2 and test 3. This study also demonstrated that, after the first test, the pacing strategy adopted in the second and third trials was repeatable, whereas Stone et al. (25) have demonstrated a consistent pacing strategy across a series of three 4000-m cycling TTs in trained cyclists. However, the influence of competition on pacing strategy remains to be systematically examined.

The optimal pacing strategy in a TT is the one that results in the fastest performance time. In contrast, head-to-head (HH) competition requires only that the winning athlete beat the other competitors. Consequently, the pacing strategy may be influenced by other athletes and could favor an end spurt to ensure that an athlete crosses the finish line ahead of other competitors. Alternatively, it has been suggested that in

Address for correspondence: Jo Corbett, Ph.D., Department of Sport and Exercise Science, University of Portsmouth, Spinnaker Building, Cambridge Road, Portsmouth PO1 2ER, United Kingdom; E-mail: jo.corbett@port.ac.uk.
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certain competitive situations, athletes may alter their pacing strategy to adopt a faster-than-usual starting pace (14). Previous studies in which participants have been instructed to adopt a fast initial exercise pace have shown improvements in performance in maximal exercise tests lasting ~2–5 min (1,5,15). In these investigations, the performance improvements were attributed to a faster oxygen uptake response, which increased the aerobic energy contribution. Similarly, Hulleman et al. (14) have reported that when individual data in a series of 1500-m cycling TTs were ranked by performance, the fastest times were characterized by a more aggressive early pace. However, the bioenergetic basis for the fastest performances in this study was attributed to a greater anaerobic energy yield during the early part of the TT, with the pattern of aerobic energy expenditure invariant across trials.

Accordingly, the aims of the present study were threefold: i) to examine the effect of simulated HH competition on 2000-m cycling performance, ii) to investigate the effect of simulated HH competition on the spontaneous pacing profile adopted, and iii) to describe the bioenergetic basis for any changes in performance or pacing profile due to simulated HH competition.

METHODS

Participants

Fourteen nonsmoking males (mean \pm SD: age = 19 \pm 1 yr, body mass = 71.5 \pm 8.7 kg, height = 1.76 \pm 0.05 m) participated in this study. All participants undertook regular physical exercise (\geq 30 min, two or more times per week) and were accustomed to exercise of a maximal nature, although none of the participants were trained cyclists. Participants provided written informed consent and completed a health history questionnaire before participation. The study was reviewed and approved by the university's ethical committee.

Experimental Design

To familiarize participants with the experimental protocol and procedures and to ensure adequate reliability, each individual undertook three preliminary 2000-m TTs while exercising alone. After the familiarization sessions, the participants undertook two further "experimental" trials: 1) a 2000-m TT while exercising alone and 2) a 2000-m simulated HH competition. The order in which subjects performed the 2000-m TT and the 2000-m simulated HH competition was counterbalanced.

Experimental Procedures

All exercise protocols were performed on the same Velotron Dynafit Pro cycle ergometer (RacerMate, Inc., Seattle, WA). Factory calibration of the cycle ergometer was verified using Velotron CS software (RacerMate, Inc.) and the Accuwatt

rundown verification procedure. Individual positional adjustments (saddle and handlebar height and position) were made before the first exercise test and were replicated for all subsequent exercise tests. Velotron 3D software (RacerMate, Inc.) was used to construct a flat 2000-m virtual racecourse, which was used for the familiarization sessions, as well as the 2000-m TT and 2000-m simulated HH competition.

2000-m familiarization sessions and TT. Identical procedures were used for the familiarization sessions and the 2000-m TT. On arrival at the laboratory, the participants were told that they would be undertaking a 2000-m TT. Participants then undertook a 5-min warm-up at 150 W, after which they were allowed 5 min to stretch and prepare themselves for the exercise task. Before commencing each 2000-m TT, the participants were instructed to complete the 2000-m distance in the fastest time possible. During the TT, a computerized image of a cyclist (generated using the Velotron 3D software) was projected onto a 200-cm \times 160-cm (width \times height) projector screen 200 cm in front of the participant, allowing the participants to watch themselves racing the 2000-m virtual course. The distance completed was displayed throughout the TT, but the participant was blinded to all other feedback (time, power, speed, HR, etc.), although it was recorded by the software and downloaded afterward for analysis. The use of the electronic gearing system was standardized during the exercise trials, and no verbal encouragement was given. A Velotron that was not in use was positioned adjacent to the participant's Velotron.

2000-m simulated HH competition. The same methods as in the 2000-m TT were used in the 2000-m simulated HH competition, with the following exceptions. On arrival at the laboratory, the participants were informed that they would be competing over the same 2000-m virtual course against another competitor of similar ability who would be exercising on an adjacent Velotron ergometer and that they should try and beat the other competitor. The participants were also informed that they would not be allowed to see the other competitor at any point before, during, or after the test to minimize possible confounding effects from perceptual cues and interpersonal rivalries. Thus, the participants were kept in separate rooms before the exercise test, whereas during the test, the cycle ergometers were separated by screens, and participants were instructed that verbal communication was not permitted. During the simulated HH competition, a computer-generated image of the participants on the same 2000-m course was displayed on the projector screen using the Velotron 3D software, enabling each participant to gauge his position on the course and relative to his competitor. In addition, the distance remaining for both participants was clearly visible throughout, and the drafting option in the Velotron 3D software was disabled. However, although the participants believed that they were competing against another competitor, in reality, the performance of the competitor was generated by the Velotron 3D software using data saved from the best performance time registered by

each participant during his 2000-m TT familiarization trials (FAM). Thus, although the participants believed they were competing against another competitor, in effect, they were competing against their previous best performance. The role of the sham competitor was played by a member of the experimental team who exercised at a moderate intensity on the other Velotron, behind the separation screen.

During the exercise tests, $\dot{V}O_2$, $\dot{V}CO_2$, and RER were recorded breath by breath (Cosmed Quark B2; Rome, Italy). The gas analyzers and flow turbine were calibrated before each exercise test using certified standard gases and room air and a 3-L syringe, respectively. Each exercise testing session was conducted at the same time of day (± 1 h) to minimize circadian variation. Trials were separated by at least 48 h, and participants refrained from strenuous exercise in the 48 h preceding each laboratory testing session as well as products containing caffeine or alcohol for 24 h before testing. In addition, participants were instructed to abstain from food consumption 2 h before each testing session and to maintain their normal diet throughout the experiment.

Data Analysis

Split times, power output (P_{tot}), HR, $\dot{V}O_2$, and $\dot{V}CO_2$ for each 2000-m TT were allocated to sequential 250-m “bins” that were used for analysis of pacing profile. The energy attributable to aerobic (P_{aer}) and anaerobic (P_{anaer}) energy sources for each bin was calculated according to the method described previously (9,14). Briefly, this method assumes that the gross mechanical efficiency determined during the fixed intensity warm-up for each participant before each exercise trial is constant across all work rates, with the trial-specific mechanical efficiency subsequently used to determine the P_{aer} corresponding to a given rate of O_2 uptake, with P_{anaer} determined by subtraction of P_{aer} from P_{tot} . Between-trials differences in pacing profile were examined by a (3 \times 8) two-way repeated-measures (trial \times distance) ANOVA; where the ANOVA violated the assumption of sphericity, the Greenhouse–Geisser statistic was used. *Post hoc* analyses of condition and interaction effects were examined by pairwise comparisons with a Student’s *t*-test. The total work (W_{tot}), total aerobic work (W_{aer}), and total anaerobic work (W_{anaer}) were calculated from the sum of the respective energy sources from the 250-m bins. Between-trials differences in performance times, W_{tot} , W_{aer} and W_{anaer} were determined by one-way repeated-measure ANOVA. *Post hoc* analysis was by the pairwise comparison method. Pairwise comparisons were used to check for the presence of an end spurt by comparison of the final two data points for P_{tot} for each TT condition. Statistical analysis was performed using SPSS (version 15.0; IBM, Armonk, NY), with CV calculated according to the method of Hopkins (13). All data are presented as mean \pm SD, unless otherwise stated. Statistical significance was accepted at $P < 0.05$, and a statistical trend was defined as $P < 0.10$.

RESULTS

Familiarization trials. The times for the three familiarization 2000-m TTs were 189.5 ± 8.4 , 188.8 ± 8.1 , and 189.2 ± 8.8 s for the first, second, and third trials, respectively. Between-trials differences in performance time were not significantly different ($P = 0.651$), whereas the CV between trial 1 and trial 2 and between trial 2 and trial 3 was 1.1% and 0.8%, respectively. Taken together, these findings indicate that the participants were well familiarized before the experimental trials.

Experimental trials. The mean gross mechanical efficiency of the participants during the 5-min warm-up at 150 W was $18.9\% \pm 0.8\%$. The times for the FAM, TT, and HH 2000-m performance trials were 187.7 ± 8.2 , 188.3 ± 9.5 , and 184.6 ± 6.2 s, respectively. A significant difference in performance times was evident between the trials ($P = 0.013$). The *post hoc* analysis indicated that the time recorded in HH was faster than that in either TT ($P = 0.021$) or FAM ($P = 0.003$). Moreover, 12 of the 14 participants were able to beat their sham competitor (i.e., FAM) during the HH condition. The two participants who were unable to beat their sham competitor “lost” the simulated HH competition by only 0.06 and 0.01 s. However, there was no difference in performance times between the FAM and TT conditions ($P = 0.486$), further supporting the assertion that the participants were well familiarized and that the improved performance in HH was not due to ordering or learning effects. Postexercise blood lactate concentrations were 16.2 ± 2.8 , 16.9 ± 2.98 , and 17.0 ± 2.48 $mmol \cdot L^{-1}$ for the FAM, TT, and HH conditions, respectively, and were not different between conditions ($P = 0.246$).

The serial pattern of P_{tot} is shown in Figure 1. Significant trial ($P = 0.002$), distance ($P < 0.001$), and trial \times distance interaction effects ($P < 0.001$) were evident. The *post hoc* analysis showed that the participants matched the FAM

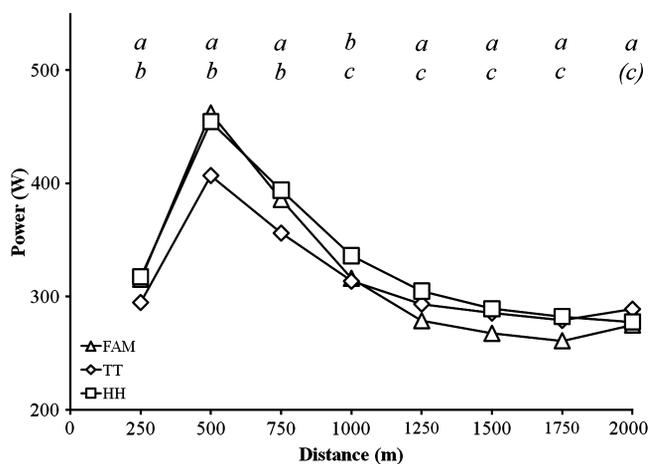


FIGURE 1—Serial pattern of P_{tot} during the FAM, TT, and HH conditions. “Significant difference between FAM and TT; ^asignificant difference between TT and HH; ^bsignificant difference between FAM and HH. Parentheses denote statistical trend. SD are omitted for clarity.

performance during the initial 750 m of the HH condition. In both FAM and HH conditions, the P_{tot} initially exceeded that of the TT condition. Subsequently, from 1000 to 1750 m participants maintained a higher P_{tot} in the HH condition than in the FAM condition, with the P_{tot} maintained at a level similar to that of TT over this latter part of the test. No end spurt was evident in either HH or TT conditions, although a significant end spurt was evident in the FAM condition ($P = 0.008$).

The serial pattern of P_{aer} is shown in Figure 2. There were no significant trial ($P = 0.403$) or trial \times distance interaction effects ($P = 0.334$), although significant changes in P_{aer} with distance were evident ($P < 0.001$). In general, the P_{aer} increased after the initial 250 m, remaining relatively constant thereafter.

The serial pattern of P_{anaer} is shown in Figure 3. The ANOVA showed significant trial ($P = 0.009$), distance ($P < 0.001$), and trial \times distance effects ($P < 0.001$). The *post hoc* analysis showed that the between-conditions differences in the serial P_{anaer} generally followed the same trends as P_{tot} , with the exception of the first 250 m, in which the P_{anaer} in HH only was higher than that in TT.

Finally, significant condition effects were evident for W_{tot} ($P = 0.004$) and W_{anaer} ($P = 0.019$) but not W_{aer} ($P = 0.153$) (Fig. 4). W_{tot} was higher in HH than in FAM ($P = 0.003$) or TT ($P = 0.007$) but not different between FAM and TT ($P = 0.150$). Similarly, W_{anaer} was higher in HH than in FAM ($P = 0.002$), with a trend for a higher W_{anaer} in HH than in TT ($P = 0.053$), but was not different between FAM and TT ($P = 0.620$).

DISCUSSION

The main findings of the present study were i) participants were able to complete the 2000-m cycling TT faster when they believed that they were competing in an HH competition than when they exercised alone; ii) the faster performance

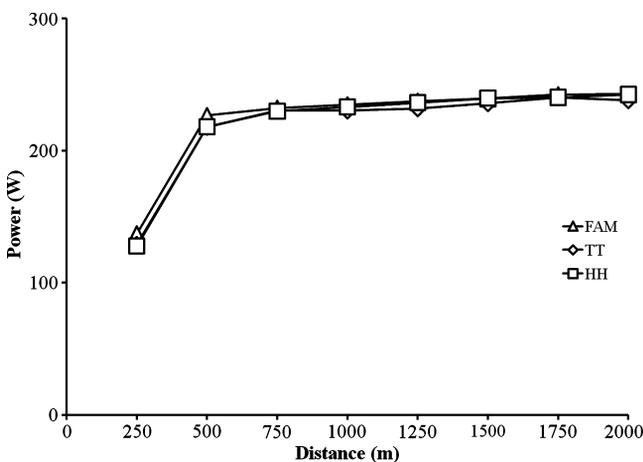


FIGURE 2—Serial pattern of P_{aer} during the FAM, TT, and HH conditions. SD are omitted for clarity.

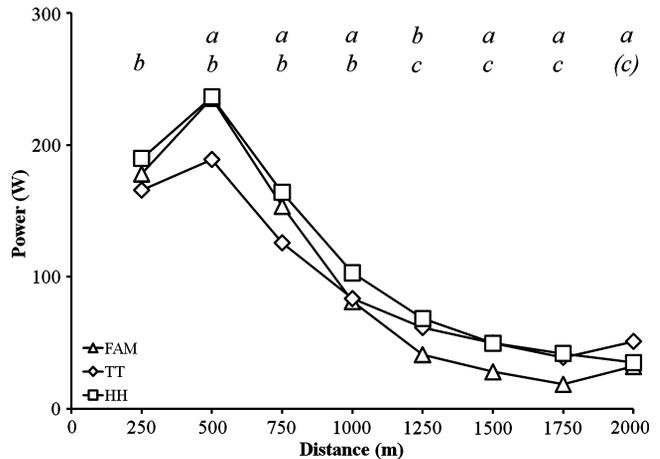


FIGURE 3—Serial pattern of P_{anaer} during the FAM, TT, and HH conditions. ^aSignificant difference between FAM and TT; ^bsignificant difference between TT and HH; ^csignificant difference between FAM and HH. Parentheses denote statistical trend. SD are omitted for clarity.

times in HH were achieved by a systematic alteration in the spontaneous pacing strategy adopted, which mirrored that of the FAM condition during the initial 750 m, before remaining significantly higher over the final 1000 m of the trial; iii) the bioenergetic basis for the performance improvement resulted from an increase in both the rate of anaerobic energy yield (during the final 1000 m) and the total anaerobic energy yield, whereas the aerobic energy contribution remained unchanged.

The improvements in performance with HH competition are consistent with other previous studies using cycling (26,28) or running (21) as the criterion task. Yet, the bioenergetic basis for these performance improvements with HH competition has seldom been considered. One of our hypotheses was that the performance improvement in HH competition might result from a faster early exercise pace, thereby accelerating $\dot{V}O_2$ kinetics and sparing the anaerobic energy

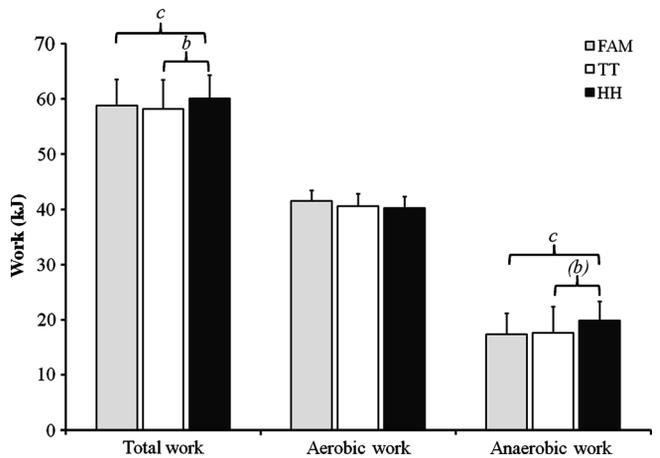


FIGURE 4— W_{tot} , W_{aer} , and W_{anaer} in the FAM, TT, and HH conditions. ^bSignificant difference between TT and HH; ^csignificant difference between FAM and HH. Parentheses denote statistical trend.

stores, in a manner similar to that which has previously been demonstrated with an “all-out” starting strategy (1,5,15). This was clearly not the case in the present study because the initial exercise pace and aerobic energy contribution were unchanged between conditions. Indeed, our finding of a greater total anaerobic energy yield in HH competition is somewhat at odds with others who have demonstrated total anaerobic energy expenditure to be invariant across cycling distances from 1000 to 3000 m (11) and running distances from 800 to 1500 m (23), findings that are consistent with predictions based on the concept of an individual maximal anaerobic energy capacity (16). An alternative explanation is that the anaerobic energy capacity is closely monitored, and as such, the rate of anaerobic energy expenditure has been shown to not reach zero during cycling TT exercise from 500 to 3000 m (9,10,12). Moreover, the increased time to exhaustion during incremental HH exercise reported by Wilmore (28) was attributed to an increased anaerobic energy contribution. The combined findings of these studies are more compatible with the present study. However, regardless of the bioenergetic basis, in order for the P_{tot} to be higher during the latter part of the HH, test motor unit recruitment must have also been increased. Although this did not result in a concomitant increased rate of oxygen uptake, there is some tentative evidence to suggest that mechanical efficiency may be altered during exercise in response to certain psychological interventions such as manipulation of the anticipated exercise end point (3); the existence of such a mechanism in the present study cannot be discounted.

Because the early exercise pace was essentially unchanged relative to FAM and no physiologic or pharmacologic intervention was administered, the performance improvement with HH competition supports the role of some psychological or “central” factor. The precise nature of such a mechanism is not entirely clear, although many psychological paradigms may be relevant. For example, the motivational intensity theory (7) implies that exercise performance is the product of a balance between the effort required to achieve a given performance and the maximum effort the subject is willing to exert or, as Noakes and St. Clair Gibson (19) assert, “the outcome of a psychological skirmish within the CNS between the sum of all negative factors such as fatigue and muscle pain, and the positive factors such as motivation and will power” (p. 21). Thus, the HH competition may have provided a sufficient motivational stimulus to positively influence this balance. However, a previous study in which participants were offered a monetary incentive if they were able to improve their best 1500-m TT performance by >1 s demonstrated no influence on performance (14), although these divergent findings might be explained by differences in the efficacy of intrinsic versus extrinsic motivational factors. Alternatively, the HH competition might have affected performance through influences on attentional focus; the perception of exertion is negatively correlated with dissociative thoughts (4), whereas external sensory input in the field of vision has been proposed to reduce the intensity of internal

sensory input (8). Similarly, the competition orientation in HH scenarios has been hypothesized to reduce the level of perceived exertion, which St. Clair Gibson et al. (24) suggest is also reduced if a leading athlete moves ahead of a group of athletes and is likely to win an event and is increased, on the other hand, when an athlete can no longer keep up with a group of athletes. Although empirical support for this statement is lacking, the manner in which the participants in the present study initially paralleled the “competitors” performance before surpassing it during the second part of the HH condition is in keeping with this assertion. Nevertheless, empirical studies in which “centrally” acting agents such as amphetamine have been administered have often shown improvements in exercise performance (6,22). Consequently, it has been argued that all exercise performances are submaximal because they are terminated before there is a catastrophic metabolic or cardiorespiratory failure and that a physiological “reserve” capacity will always remain (20). The ergogenic effects of the HH competition might therefore result from the central influence of some motivational or dissociative effect enabling the use of a greater degree of the physiologic “reserve” capacity.

Although significant between-conditions differences were evident in the pacing strategy adopted in the present study, in the main, the spontaneous pacing strategies adopted were similar, being characterized by an initial peak in P_{tot} during the first 500 m followed by a progressive reduction in P_{tot} over the remainder of the exercise task. In general, this type of pacing strategy is regarded as being most favorable for short-duration events in sports where drag forces are relatively low (9) because a fast initial exercise pace will reduce the time taken to overcome the inertia associated with accelerating from a standing start, while maximizing the kinetic energy generated. Nevertheless, although a higher initial P_{tot} was adopted in FAM than in TT, this was balanced by the lower power, relative to FAM, in the latter part of the trial, with the consequence that performance times were similar in these conditions. The observation that the fastest familiarization trial was characterized by a high initial P_{tot} is consistent with previous research examining the within-participant characteristics of the fastest performance times in serial trials (14), whereas we have previously described a systematic change in pacing profile after the first TT during repeated 2000-m TTs, with no change in overall performance times (9). It was hypothesized that the change in pacing strategy adopted was not solely for performance reasons and may have been related to minimizing the disruption of the internal milieu by adopting a more conservative early exercise pace, while producing an “acceptable” performance outcome.

Despite our contention that the improved performance in HH is indicative of some “central” limiting factor, the progressive reduction in P_{tot} observed in this condition and the absence of an end spurt have previously been suggested as being more consistent with “peripheral” models of fatigue (27). However, it has been argued that peripheral changes in

metabolite accumulation or phosphagen depletion would still be centrally monitored, via afferent feedback, in advance of these changes becoming critical or harmful and that the pacing strategy is regulated in the presence of a falling work output (9). This assertion would seem compatible with the maintenance of a higher P_{tot} in HH than in FAM over the latter part of the test, despite a near identical initial power profile and a falling P_{tot} in each instance.

It should be noted that the present study was not without limitation. The model used in the present study, in which participants competed against their own previous best performance, may have created a somewhat artificial competitive scenario, which might have precluded against participants adopting pacing strategies substantially different from the FAM condition. It remains to be investigated if a similar systematic alteration in pacing profile would be evident in a genuine HH competition. Nevertheless, there were also many benefits of the experimental model that was used. For instance, it enabled a degree of standardization of the “competitor” during the HH condition, it ensured that the participant and competitor should have been equally well matched in all HH trials, and it negated the possible confounding influence of interpersonal rivalries. Although excellent intrasubject reliability was demonstrated for the solo exercise conditions (familiarizations and HH), the use of a moderately trained group of male participants who are not engaged in competitive cycling may limit the applicability of this study to other more elite populations as well as female athletes. It might be hypothesized that highly motivated elite individuals are able to use a greater amount of their physiologic “reserve” capacity, regardless of whether they exercise alone or against another competitor. Further research would be needed to confirm this hypothesis. Finally, certain assumptions were made concerning the constancy of mechanical efficiency across a range of P_{tot} and muscle O_2 desaturation. These assumptions have been discussed

previously (10) and seem broadly justified (17), although any error should be similar within subjects across the exercise trials. The observation that blood lactate concentration did not differ between conditions seems at odds with calculated anaerobic energy contribution. However, blood lactate values are dependent on many factors, including the balance between production and clearance, the rate of efflux from muscle, and total body water content. As such, blood lactate concentration provides only a crude index of anaerobic work, which may not have been sufficiently sensitive to detect the magnitude of difference detected using other methods in the present study.

In summary, the present study has shown that moderately trained participants were able to complete a 2000-m cycling task more quickly in an HH competition than when they exercise alone. The initial exercise pace in the HH competition initially mirrored that of the FAM condition, with a higher exercise pace maintained in the second half of the trial. Although a different pacing strategy was adopted in FAM and TT, the performance times were not significantly different. The bioenergetic basis for the performance improvement resulted from an increase in both the rate of anaerobic energy yield (during the final 1000 m) and the total anaerobic energy yield, whereas the aerobic energy contribution remained unchanged. Because the early exercise pace was essentially unchanged relative to FAM and no physiologic or pharmacologic intervention was administered, the present study implicates the role of some “central” factor in mediating the observed performance improvement with HH competition. Future studies should try and elucidate the precise nature of these central mechanisms.

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The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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