Effect of task familiarisation on distribution of energy during a 2000 m cycling time trial

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ABSTRACT

**Aim:** To investigate the effect of task familiarisation on the spontaneous pattern of energy expenditure during a series of 2000 m cycling time trials (TTs).

**Method:** Nine trained males completed three 2000 m TTs on a Velotron cycling ergometer. To examine pacing strategy, the data were assigned to 250 m “bins,” with the pattern of aerobic and anaerobic energy expenditure calculated from total work accomplished and gas-exchange data.

**Results:** There were no significant differences between trials in performance times (191.4 (SD 4.3), 189.4 (4.6), 190.1 (5.6) s), total aerobic (58.3 (2.7), 58.4 (3.1), 58.0 (3.4) kJ) and total anaerobic energy expenditure (16.4 (3.3), 17.3 (2.8), 16.5 (3.1) kJ). Pacing strategy in the second and third TT differed from the first TT in that a lower power output was adopted during the first 500 m, enabling a higher power output during the final 750 m of the TT. This adjustment in the pattern of energy expenditure was mediated by an alteration in the pattern of anaerobic energy expenditure, which paralleled changes in total energy expenditure. Furthermore, participants retained an anaerobic energy “reserve” enabling an end-spurt during the second and third trials.

**Conclusion:** Small modifications to the pacing strategy are made following a single bout of exercise, primarily by altering the rate of anaerobic energy expenditure. This may have served to prevent critical metabolic disturbances. The alteration in pacing strategy following the first exercise bout is compatible with a complex intelligent regulatory system.

Pacing strategy refers to the spontaneous variation of speed during self-paced exercise. It has been proposed that these variations in speed are primarily determined by motor unit recruitment, which is controlled by a brain pacing-centre employing a feed-forward mechanism incorporating knowledge of the estimated exercise endpoint together with memory of prior events of similar distance and duration, in order to generate the appropriate exercise pace.1–3 During exercise the pace may be modified by altering efferent motor command, based upon feed-back loop control using afferent information, in order to prevent catastrophic failure in any physiological system before reaching the exercise endpoint.2,4–8

It has been suggested that the motor unit sequences utilised by a brain pacing-centre would be programmed into the motor cortex from childhood9 and that the ability to monitor energy resources is learnt early in an athlete’s experience and is not highly specialised.7 This assertion is supported by Laursen et al10 who have shown a low coefficient of variation (5.3%) for two 1500 m runs in a group of runners who specialised in competing at longer distances (5 km to half-marathon). Similarly, Foster et al11 have shown closely matched mean performance times for three 1500 m cycling TTs (133.8 (SD 6.6) s; 133.9 (5.8) s; 133.8 (5.5) s), despite the participants not being specifically trained for this distance. Moreover, it has been suggested that if pacing strategy is dependent upon a pre-established template utilising the memory of prior events of similar distance and duration, and athletes typically have a long experience in developing that template, then it may take either a very long time or an unusually high motivation to modify the pacing strategy.7 Indeed, the stability of pacing strategy and performance times during exercise is further demonstrated by a recent study in which cyclists were unable to improve their time for a 1500 m cycling TT despite the offer of a monetary incentive ($100), paid if they were able to beat their best time by >1 s.12

Nevertheless, a meta-analysis indicates that in studies using three or more trials, the variability in performance between the first two trials was 1.3 times that of subsequent trials, whereas performance improved 1.2% between the first two trials but only 0.2% between subsequent trials;13 findings that are consistent with fitness, skill or motivation effects arising from the first trial.14 Interestingly, despite the suggestion that pacing strategy should be well learnt in highly trained athletes who are familiar with a certain exercise task,15 it appears that this effect is also evident in elite athletes. Schabort et al16 demonstrated an improvement in mean power of 2.3% from trial 1 to 2 and 0.9% from trial 2 to 3 in a series of 2000 m rows, in highly trained athletes that were familiar with regular rowing ergometer testing. These improvements were attributed to the adoption of a more even pacing strategy in the second and third trial, although this was not systematically examined. Similarly, although mean performance times were almost identical in the study of Foster et al11, it was suggested that pacing strategy was modified, with a reduced power output in the first 100 m of the second and third trials relative to the first exercise trial, although this was not analysed statistically.

These findings suggest that significant pacing information might be gained from an initial bout of exercise, which is used to modify the pattern of energy expenditure during subsequent bouts of exercise. This assertion is compatible with the concept of an intelligent, complex system regulating the exercise pacing strategy.1,6 However, it is unclear as to how any modifications in spontaneous pacing strategy might affect the distribution of energy from aerobic or anaerobic resources,
although previous studies in which participants were instructed to vary their pacing strategy by adopting an unusually fast or slow starting pace have shown that these changes were primarily met by altering the pattern of anaerobic energy distribution.12 13 However, to our knowledge the effect of task familiarisation on the spontaneous pattern of energy expenditure during subsequent exercise bouts has not been systematically examined. Accordingly, the aim of the present study was to investigate the effect of task familiarisation on the spontaneous pattern of energy expenditure during a series of 2000 m cycling TTs, with specific reference to the partitioning of energy derived from aerobic and anaerobic sources.

METHOD

Participants
Nine non-smoking males participated in this study. All participants regularly undertook exercise (>30 min, >2 × week), and were accustomed to exercise of a maximal nature, although none of the participants were trained cyclists. The participants’ mean (SD) age, body mass, height were: 18.7 (0.7) years, 68.3 (6.0) kg and 1.75 (0.06) m, respectively. Participants provided written informed consent and completed a health history questionnaire prior to participation. The study was approved by the University’s Ethical Committee.

Experimental design
Each participant undertook three 2000 m cycling TTs. Each of the exercise testing sessions was conducted between 1200 and 1600 h, in order to minimise circadian variation. Participants were instructed to maintain their normal diet throughout the experiment and to refrain from strenuous exercise in the 48 h preceding each laboratory testing session and to abstain from any products containing caffeine or alcohol for 24 h prior to testing. All tests were completed within a 2-week period.

Experimental procedures
Exercise testing was performed in an air-conditioned laboratory with a temperature of 19.5 (1.0)°C and relative humidity of 43 (8)%. Height, body mass and blood pressure were recorded on the first attendance, prior to commencing exercise. All exercise was performed on the same Velotron Dynafit Pro electrically braked cycle ergometer (RacerMate, Seattle, Washington), which has been shown to provide reliable14 and valid power measurement.15 Factory calibration of the cycle ergometer was verified prior to each exercise trial using CS software (RacerMate) and the “Accuwatt” run down verification procedure. Individual positional adjustments (saddle and handlebar height and position) were made prior to the first exercise test and were replicated for all subsequent exercise tests.

Prior to the 2000 m TT, participants 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. A 2 km TT flat 2 km “virtual” race course was constructed using Velotron 3D software (RacerMate) and was used for all time trials. Before commencing the 2000 m TT, the participants were instructed to complete the 2000 m distance in the fastest time possible. During the TT, a computerised image of a cyclist (generated using the Velotron 3D software) was projected onto a 200 cm×160 cm (width × height) projector screen 200 cm in front of the participant, allowing the participants to watch themselves on the “virtual” course. The distance completed was displayed throughout the time trial, but all other feedback (time, power, speed, heart rate, etc) was blinded to the participant, although it was recorded by the software and downloaded afterwards for analysis. The use of the electronic gearing system was standardised during the exercise trials, and no verbal encouragement was given. The same experimenters were present during each testing session.

During the exercise tests, VO2, VCO2 and RER were recorded breath by breath (Cosmed Quark B2, Rome). The gas analysers and flow turbine were calibrated prior to each exercise test using certified standard gases (16.00% O2, 5.00% CO2) and room air, and a 3 litre syringe, respectively. Heart rate was recorded throughout exercise using short-range telemetry (Polar T61, Kempele, Finland), interfaced with the Velotron 3D software. Three minutes after the completion of each exercise test, a fingertip capillary blood sample was obtained and assayed for blood lactate concentration (Biosen C Line Sport, Barleben, Germany).

Data analysis
Split times, power output (P tot), heart rate, VO2 and VCO2 for each 2 km TT were allocated to sequential 250 m “bins” which were used for analysis. The energy attributable to aerobic (P aer) and anaerobic (P anaer) energy sources was calculated according to the method described previously,7 9 16 with gross efficiency calculated from the respiratory data recorded during the final 2 min of the warm-up at 150 W.

Statistical analysis
Statistical analysis was performed using SPSS (version 15.0). All data are presented as mean (SD), unless otherwise stated. Statistical significance was accepted at p<0.05, and a statistical trend accepted at p<0.10. A 3×8 (TT×distance) repeated-measures ANOVA was used to compare P tot, P aer and P anaer. One-way repeated-measures ANOVA was used to investigate between TT differences in the total performance times, total work accomplished, total aerobic work, total anaerobic work, gross efficiency, peak VO2, peak heart rate and postexercise blood lactate concentration. Where the ANOVA revealed a significant effect, this was investigated post-hoc using pairwise comparisons. To check for the presence of an end-spurt, a paired samples t test was conducted to investigate differences between the final and penultimate 250 m for each trial for P tot, P aer and P anaer. The between-TTs coefficient of variation was calculated according to the method of Hopkins.17

RESULTS
The mean times for the 2000 m TTs were 191.4 (4.3) s, 189.4 (4.6) s and 190.1 (5.6) s for the first, second and third trials respectively. The differences in performance times between the TTs were not significant. The CV for trial 1 and 2 was 1.1%, and for test 2 and 3 0.9%, indicating good test–retest reliability.

The total work accomplished was not significantly different between the 2000 m TTs (58.3 (2.7) kJ, 58.4 (3.1) kJ, 58.0 (3.4) kJ, for the first, second and third TT respectively). Similarly, there were no significant differences between the 2000 m TTs in total aerobic work (41.9 (2.7) kJ, 41.1 (1.5) kJ, 41.5 (2.4) kJ for the first, second and third TT respectively) or total anaerobic work (16.4 (3.3) kJ, 17.5 (2.8) kJ, 16.5 (3.1) kJ for the first, second and third TT respectively). The serial patterns of P tot, P aer, P anaer for each of the trials are shown in figures 1, 2, 3 respectively. Although there were no significant differences between trials for any of these parameters, a significant trial-by-distance interaction effect was evident for P tot and P anaer. Post-hoc analysis showed that these interaction effects were generally characterised by a reduction in P tot and...


**Panaer** during the early part of the second and third trials, relative to the first trial, with a concomitant increase in $P_{tot}$ and $P_{anaer}$, relative to trial 1, during the latter part of the test. Moreover, there was a significant increase in $P_{tot}$ and $P_{anaer}$, but not $P_{aer}$, over the final 250 m in TT 2 and 3, indicating the presence of an end-sprint in these trials.

Gross efficiency, peak heart rate, peak VO$_2$, and post-exercise lactate concentration, for each of the trials are shown in table 1. There were no significant differences between trials for any of these parameters.

**DISCUSSION**

The aim of the present study was to investigate the effect of task familiarisation on the spontaneous pattern of energy expenditure during a series of 2000 m cycling TTs, with specific reference to the partitioning of energy derived from aerobic and anaerobic sources.

Our results indicate that an adjustment was made in pacing strategy following the first TT, which was characterised by a reduction in power output during the first 500 m, and the maintenance of a higher power output during the final 750 m, in both the second and third TT. This was paralleled by changes in the pattern of anaerobic energy expenditure, which generally followed the alterations in power output. This finding is consistent with previous studies showing that variations in power output caused by adopting an unusually fast or slow starting pace were met primarily through altering the pattern of anaerobic energy distribution. However, we speculate that the bio-energetic changes shown in our study, and in previous studies, are secondary to alterations in the motor unit recruitment patterns, although this was not measured in the present study. Despite the change in the pattern of anaerobic energy expenditure following the first TT, there were no differences between TTs in the total anaerobic energy expenditure, a finding that might be interpreted as consistent with the concept of a fixed individual maximal anaerobic energy capacity. However, similar to previous studies investigating 1500 m and 2000 m cycling TT performance, the anaerobic energy contribution in the present study never reached zero, which supports the suggestion that athletes monitor some aspect of anaerobic energy expenditure during high-intensity exercise to ensure that near zero values are not reached until the finish line is approached.

Taken together, the findings of the present study are generally compatible with a complex-intelligent regulatory pacing mechanism, as described by the Central Governor Model (CGM), rather than a catastrophe model of fatigue, in which pacing strategy is dictated by metabolite accumulation and the development of peripheral fatigue. According to the CGM, the initial exercise pace is set by a brain pacing-centre “in anticipation” of the exercise task, using a feed-forward mechanism incorporating knowledge of the estimated exercise endpoint together with memory of prior events. Thus, we speculate that the information gained from the first TT was
utilised to consciously, or subconsciously, decrease the early exercise pace during the second and third TTs, presumably as a consequence of a change in the motor unit recruitment pattern in the exercising muscle. The observation that this was achieved specifically by a reduced rate of anaerobic energy expenditure raises the possibility that this might have been mediated by changes in type II muscle fibre recruitment. Moreover, we contend that this alteration in pacing strategy is not compatible with a catastrophe model of fatigue, which predicts that in the absence of any change in physical ability an identical pacing profile would be evident on each occasion. Likewise, any change in physical ability would manifest in the maintenance of a higher or lower power output throughout the TT, with a similar decay in power evident as the accumulation of deleterious metabolites increased. Clearly this was not the case in the present study.

In accordance with the CGM, the modification in initial pacing strategy would serve to optimise the distribution of energetic resources while preventing critical metabolic disturbances. Indeed, the participants were able to sustain a higher power output during the latter part of the second and third TT, presumably because homeostasis had been better maintained by the slower early exercise pace and lower initial rate of anaerobic energy expenditure in these trials. Nevertheless, there was a progressive reduction in power output after 500 m in each of the TTs; a pacing characteristic that is purported to be more compatible with a catastrophe model of fatigue. However, an alternative proposal, consistent with the CGM, is that intracellular changes in metabolite accumulation or phosphagen depletion might be centrally monitored, via afferent feedback, in intracellular changes in metabolite accumulation or phosphagen depletion might be centrally monitored, via afferent feedback, in

| Table 1 Gross efficiency, peak heart rate, peak VO2 and postexercise lactate concentration for the first, second and third time trial |
|------------------|--------|--------|--------|
|                   | 1      | 2      | 3      |
| Gross efficiency (%) | 18.5 (1.7) | 19.0 (0.6) | 18.9 (1.0) |
| Peak heart rate (bpm) | 192 (7)  | 191 (6)  | 190 (4)  |
| Peak VO2 (l/min)    | 3.75 (0.34) | 3.65 (0.17) | 3.67 (0.23) |
| Postexercise lactate (mmol/l) | 17.3 (3.4) | 16.9 (2.5) | 16.6 (2.9) |

In summary, to our knowledge the present study is the first to systematically evaluate the changes in the spontaneous pattern of aerobic and anaerobic energy contribution during repeated performance of an exercise task. An adjustment in pacing strategy was evident following the first TT, which was characterised by a lower initial power output, which enabled the participants to maintain a higher power output in the latter part of the test. This alteration in pacing strategy appeared to be mediated primarily by adjustment in the pattern of anaerobic energy distribution. The alteration in pacing strategy following an exercise bout is compatible with the Central Governor Model.

**What is already known on this topic**

Previous studies suggest that athletes may modify their pacing strategy during repeated exercise trials. This effect may be evident in the absence of any performance changes. Presently it is unclear as to how spontaneous changes in pacing strategy influence the distribution of energy from aerobic or anaerobic resources.

**What this study adds**

Alterations to pacing strategy were evident following a single bout of exercise. This was mediated by altering the rate of anaerobic energy expenditure, although this may be secondary to changes in motor unit recruitment. The alteration in pacing strategy following an exercise bout is compatible with the Central Governor Model.

**Competing interests:** None.

**Ethics approval:** Ethics approval was provided by the University of Portsmouth Biosciences Ethical Committee.

**Patient consent:** Obtained.
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