Title

Prior exercise reduces fast-start duration and end-spurt magnitude during cycling time-trial

Abstract

We examined the pacing strategy and the magnitude of the end spurt during a 200-kJ cycling time trial performed 12-14 h after an exercise protocol designed to reduce muscle glycogen content. Nine physically-active men performed five familiarization sessions and two experimental 200-kJ time trials in either a control condition (CON) or after an exercise protocol performed the previous evening that was designed to induce muscle glycogen depletion (EP). Mean total time was faster and power output was higher in the CON than in the EP ($P < 0.01$). A fast-start was maintained until the 50-kJ section in CON, but only the 25-kJ section for EP ($P < 0.05$). The power outputs during the 50-, 150- and 200-kJ sections, and the magnitude of the end-spurt, were significantly higher for the CON than for the EP condition ($P < 0.05$). There was no significant difference in the rating of perceived exertion (overall and legs feelings) between conditions. In conclusion, a protocol designed to decrease muscle glycogen stores reduced the duration of the fast-start and the magnitude of the end spurt during a 200-kJ cycling time trial, impairing the overall performance.

Keywords: Sports Performance; Pacing Strategy; Carbohydrate-restricted diet; Glycogen; Physical Effort; Perceived Exertion.

Introduction

In order to reach the endpoint of a time trial as fast as possible, competitors adopt some type of pacing strategy [2,25]. During cycling time trials lasting from 5 to 20 min (medium-duration cycling time-trial), athletes naturally tend to adopt a fast start followed by a gradual decline in power output before completing the time trial with an “end spurt” [2]. A fast-start is believed to improve performance by accelerating VO_2 kinetics and increasing the total amount of aerobic adenosine triphosphate available to support the exercise [6]. This increase may spare the initial use of anaerobic energy reserves making more anaerobic energy available for the end spurt [23]. However, while a number of studies have investigated the physiological response to a fast-start [3,10], much less is known about the mechanisms controlling the end spurt.

A few studies have suggested that a gradual decline in power output after a fast-start ensures that the maximal rating of perceived exertion (RPE) is not attained before the end of exercise, and precludes an early critical depletion of energy substrates that are used during the end-spurt [11,24]. In particular, since the energy to sustain high-intensity exercise such as the end spurt is principally derived from muscle glycogen stores [35], the ability to produce an end spurt may be related to the muscle glycogen stores at the start of the end spurt [29]. In support of this, several studies have shown that pre-exercise glycogen concentration is a regulator of glycogenolysis and that low initial muscle glycogen stores reduce glycogenolytic rate [8,31,32].

One way to test this hypothesis would be to reduce muscle glycogen stores before the time trial using validated protocols [14,15,19] and to investigate if this reduces the magnitude of the end spurt. This kind of study has not been performed using a medium-duration cycling time-trial, although there is some evidence that power output during the last part of a longer-duration cycling time-trial (3 h) is impaired after a low-CHO diet [22]. However, this effect was not analysed statistically, and the effect of muscle glycogen

depletion on the magnitude of the end spurt during a medium-duration cycling time trial has not been systematically examined. Furthermore, most studies with CHO availability have focused on investigating its effects on performance during time-to-exhaustion tests [8,14,15,26]. However, time-trials appear to be more reliable and to have a greater external validity compared to constant-workload test until exhaustion [5]. Therefore, the main aim of the present study was to examine the effects of a validated muscle glycogen depletion protocol on pacing strategy and the magnitude of the end spurt during a medium-duration cycling time trial. We hypothesized that the implementation of a prior muscle glycogen depletion protocol would reduce the magnitude of the end spurt, when compared to a control condition.

Methods

Participants

Nine physically-active men but not athletes (age 24.5 ± 3.5 years, height 174.6 ± 5.3 cm, body mass 69.8 ± 4.5 kg, maximal power output 267.0 ± 32.4 W, as determined in an incremental test performed in a cycle ergometer, see below) participated in this study. All participants were engaged in a regular exercise program that involved high-intensity cycling exercise, but were not highly trained in any particular sport. The participants were familiar with cycling time-trials and laboratory testing procedures via participation in other studies in our laboratory. The sample size required was estimated, as suggested by Hopkins [21], using a coefficient of variation equal to 1.9% [33] and a very conservative expected change of 2% of the magnitude of effect [29]. The protocol, benefits, and risks were explained and written consent was obtained. The study was conducted in accordance with the ethical standards of the IJSM [17] and was approved by the Ethics and Research Committee of the Federal University of Alagoas.

Experimental protocol

During the first visit, participants underwent anthropometric measures and an incremental test to establish maximal power output (W_{max}). The incremental test started with a 3-min warm-up at an initial power output of 100 W, followed by 30 W increases every minute until exhaustion. The W_{max} was determined as the highest power output reached with a pedal frequency between 70–80 rpm. When the highest power output was not supported for a full minute, the W_{max} was calculated by interpolated power output for fractions of the terminal minute, i.e. last completed stage (W) + time in last stage (s)/60 x 30 (W). Sixty minutes after the completion of the incremental trial, the participants performed a familiarization trial. At the second and third visits (72 h apart), participants performed four more familiarization trials (two per session, each separated by 60 minutes). One week after the last familiarization session, the participants performed the two experimental trials in a random, counterbalanced order (fourth and fifth visits). One experimental trial was a control (CON), whereas another was performed 12-14 h after an exercise protocol designed to reduce muscle glycogen content (EP). There was a 1-week “wash-out” period between the experimental trials [16]. One week before a given experimental session (CON or EP), participants were asked to maintain their regular training program and replicate this in the week before (wash-out period) the subsequent experimental session. Participants were asked to refrain from exercise, alcohol, and caffeine for 24 h before each experimental session and were blinded to the objectives of this study. In addition, for the 24 h before a given experimental session (CON or EP), participants recorded their food and fluid intake and were instructed to replicate these in the 24 h before the subsequent experimental session. All trials were performed on an electromagnetically-braked cycle ergometer (Ergo Fit 167, Ergo-FitGmbH & Co., Pirmasens, Germany). Before the study had started, the cycle ergometer was calibrated by institutional biomedical engineering department. In addition, we have tested the reproducibility of our time-trial using familiarization session two and four, which were performed in a full-rested condition, and we found a typical error for mean power output of the 4.4% (90% Confidence limits: 3.1 to 8.0%) [21]. There was also no significant

difference for mean power output during the 200-kJ time trial in familiarization rides two and four (191.3 ± 32.8 W and 197.5 ± 36.4 W, respectively, P > 0.05).

Exercise protocol to reduce muscle glycogen content

In order to perform an exercise protocol to reduce muscle glycogen content, participants arrived at the laboratory at least two hours after their last evening meal (between 6:00 and 8:00 PM) before the EP trial [30]. Participants cycled for 90 min at a power output corresponding to 70% of their W_{max} (186.9 ± 22.7 W), followed immediately by six 1-min exercise bouts at 125% W_{max} (333.8 ± 40.4 W) interspersed with 1-min rest periods. Similar protocols to that used here have shown a reduction in muscle glycogen content that ranged from 50 to 70% of pre-exercise values [14,15,19]. The participants then fasted until the following morning of the EP trial. Participants in the CON condition were also asked to refrain from food for the same duration (10-12 h overnight fast), but did not perform any exercise or muscle depletion protocol in the evening before the trial. We chose to use a 10-12 h overnight fast to avoid any muscle glycogen replenishment.

Experimental trials

Experimental trials were conducted in the morning (between 8:00 and 10:00 AM). One hour before, the participants consumed a standardized breakfast containing low CHO (~10%) for the EP condition or normal CHO (~60%) for the CON condition. Participants performed a 5-min cycling warm-up at 100 W and then rested for 5 min. Thereafter, they were required to complete a 200-kJ time trial as fast as possible. The 200-kJ cycling test was chosen to approximate the duration of a medium-duration cycling time-trial (~10-15 min). The rating of perceived exertion (RPE) was recorded at every 25-kJ interval using the Borg 15-point scale [7]. Participants were asked to report a peripheral RPE using cues from joints and muscles of the legs (RPE_{legs}) and an overall RPE using cues derived from all sensations experienced during exercise ($RPE_{overall}$). Participants were blinded to elapsed time, but were able to see their accumulated work and instantaneous power output.

In the first analysis, we pooled the power output data for start, middle and finish intervals (0-50, 50-175 and 175-200 kJ, respectively) to have a more discreet data representation. Then, we analysed the data for each 25-kJ interval (0-25, 25-50, 50-75, 75-100, 100-125, 125-150, 150-175, 175-200 kJ intervals) to have a more detailed analysis of pacing. The magnitude of the end spurt for each trial was also calculated by subtracting the power output during the 175-200 kJ interval by the power output during the 150-175 kJ interval.

Statistical Analyses

Time-trial performance, mean power output, magnitude of the end spurt and mean RPE during each time-trial were compared between CON and EP using a paired t-test (95% Confidence Interval, CI). Any possible order effect concerning these variables was also tested by a two-way ANOVA with repeated-measures (condition x order). A two-way ANOVA with repeated-measures (condition and work performed) was used to compare the power output and RPE during the 200-kJ time trials. Where assumptions of sphericity were violated, the critical value of F was adjusted by the Greenhouse–Geisser epsilon value from the Mauchley test of sphericity. Post-hoc comparisons were made using a paired Student's t-test. Effect size (ES, 95% CI) was calculated as the difference between the mean of CON and the mean of EP outcomes divided by the pooled SD of the two conditions. The Hedges correction (Hedges's g) was used to account for potential bias resulting from the small sample sizes. The effect sizes of 0.2, 0.5 and 0.8 were considered as small, moderate, and large, respectively [9]. All analyses were performed using SPSS (13.0) software and the statistical significances were accepted at $P < 0.05$.

Results

Mean total time was lower (t = -3.230, 95% CI -3.2 to -0.5, ES = 0.31, 95% CI 0.13 to 0.48, $P < 0.05$) and mean power output was higher (t = 5.062, 95% CI 12.1 to 33.3, ES =

0.44, 95% CI 0.26 to 0.62, P < 0.05) in CON than in EP (table 1). The CON test was performed at 76.0 ± 6.0% of the maximal power output, which was significantly higher (P < 0.05) than in EP (67.1 ± 8.7%). There were no differences for $RPE_{overall}$ (*t* = -0.335, 95% CI -1.0 to 0.7, P > 0.05) and RPE_{legs} (*t* = -0.441, 95% CI -0.6 to 0.4, P > 0.05) between CON and EP. There was no significant effect of the order of testing for any of these variables (P > 0.05).

The mean power output at the start of the time trial (fig. 1a) was not significantly different between the conditions (*t* = 1.728, 95% CI -8.5 to 54.9 W, ES = 0.34, 95% CI -0.04 to 0.71, P = 0.128). However, the mean power output during the middle (*t* = 2.947, 95% CI 3.1 to 27.9, ES = 0.34, 95% CI 0.15 to 0.57, P < 0.05,) and finish (*t* = 4.750, 95% CI 29.0 to 86.5, ES = 0.76, 95% CI 0.41 to 1.11, P < 0.05), was significantly higher in the CON than in the EP condition. The difference in power output between CON and EP was significantly greater in the finish than in the middle (-22.0 ± 13.3% *vs* -9.1 ± 9.0%, *t* = 3.150, 95% CI 3.2 to 22.5, P < 0.05). The magnitude of the end spurt was also significantly lower in EP than in CON (*t* = -2.553, 95% CI -108.6 to -4.2, ES = 0.82, 95% CI 0.11 to 1.53, P < 0.05). In addition, there was no significant order effect of testing for any of these variables (P > 0.05).

When the data were analysed during each 25-kJ interval, there was a significant main effect for work performed and condition (P < 0.05), but there was no interaction effect (P > 0.05). The values for power output during the 50-75, 150-175 and 175-200 kJ intervals were significantly higher (P < 0.05) for the CON than for the EP condition (fig. 1b). In both, the power output during the 0-25 kJ interval was significantly higher (P < 0.05) than the power output during the 125-150 and 150-175 kJ intervals. The power output during the 175-200 kJ interval was significantly higher than all previous intervals (P < 0.05), except the 0-25 kJ interval (P > 0.05).

There was no significant difference in the $RPE_{overall}$ and RPE_{legs} between the conditions and no interaction effect ($P > 0.05$), but $RPE_{overall}$ and RPE_{legs} values increased significantly as a function of the work performed (fig. 2a and 2b, $P < 0.05$).

Discussion

The main aim of the present study was to investigate the effects of a protocol that has previously been reported to reduce muscle glycogen content [14,15,19] on the magnitude of the end spurt during a 200-kJ cycling time trial. The results indicated that 12-14 h following the protocol designed to reduce muscle glycogen stores there was a small, but significant, decrease in the power output during the middle of the race, and an even greater decrease in the magnitude of the end spurt. The duration of the fast-start was also reduced during the EP condition. Nevertheless, $RPE_{overall}$ and RPE_{legs} were very similar in both conditions.

Using time-to-exhaustion protocols (open-loop exercise), it has previously been demonstrated that performance during high-intensity exercise (80-90% of VO_2peak; 10-20 min) is impaired if athletes start the test after a muscle glycogen depletion protocol [26,27]. However, no previous study has investigated these effects during closed-loop, high-intensity exercise. This is an important distinction as there are no races in which athletes have to ride for as long as possible. To the best of our knowledge, the present study is the first to demonstrate that a prior muscle glycogen depletion protocol reduces medium-duration cycling time-trial performance. The impairments in performance time (~11%) observed in this study could be attributable to the different pacing model adopted in the EP condition, whereby the participants adopted a shorter, fast-start strategy and produced a more conservative end spurt.

We found no significant difference in power output in the first 0-25 kJ interval between CON and EP. However, the participants in the CON condition continued to apply a high power output during the 25-50 kJ interval, while there was a significant reduction in the EP

condition. This suggests that impairment in the ability to sustain the fast-start may be responsible for a part of the reduction in overall performance. This supports previous research suggesting that any time lost during the first part of a time trial cannot be recovered later in the event [3,6].

Although the glycogenolytic rate has not been formally tested in the present study, it is reasonable to suggest that the reduced power output from 25-50 kJ may be a result of a reduced glycogenolytic rate [18]. Rauch et al. [29] showed that a CHO-loaded state increased pre-exercise muscle glycogen content, and it enabled the participants to use all the additional muscle glycogen stored throughout a 60-min time trial. The power output was already reduced within the first 120 seconds of starting the time trial in the non-CHO-loaded condition. As our participants commenced the time-trial in the EP condition after undertaking a validated muscle glycogen depletion protocol, it is likely that the reduction in power output observed in the 25-50 kJ interval can be at least partly attributable to a reduced glycogenolytic rate [8,29].

The power output during the middle section of the race was also impaired in the EP condition. However, it seems attributable to the accumulation of small non-significant differences in power output between the CON and EP during the 50-75 to 150-175 kJ intervals, with the exception of the 125-150 kJ interval which was significantly different between conditions. A direct comparison between our findings and those reported in the literature should be done with caution due to considerable differences in the time-trial duration [22,29]. For example, Rauch et al. [29], utilizing a 60-min time trial, found that the power output during the middle of the trial was higher for the high-CHO than for the control. On the other hand, Johnson et al. [22], investigating the pacing strategy in a 3-h time trial, reported that there was no difference during the first 2 h of the trial between high- and low-CHO diets. Collectively, these results suggest that the effects of CHO manipulation on the middle section of a time trial may depend on the duration of the time trial.

Although the muscle glycogen depletion protocol had a small negative effect on performance during the middle of the race (reduction of ~ 9% in relation to the CON, ES = 0.34), its greatest effect was during the last part of the race (reduction of ~ 22% in relation to the CON, ES = 0.76). Also, the magnitude of increase in the power output during the last 25-kJ in the EP condition was considerably lower than in the CON condition and the effect was considered large (ES = 0.82). This supports our hypothesis that a muscle glycogen depletion protocol would have a negative effect on the magnitude of the end spurt. Bosch et al. [8] found that high rates of muscle glycogen breakdown could be maintained throughout a 180-min constant load test at 70% of VO_2max when the trial was performed in a CHO-loaded state, but decreased considerably after 60 min of exercise in the non-CHO-loaded state, when muscle glycogen content had declined. It therefore seems reasonable to suggest that the reduction in the magnitude of the end spurt found in the present study may be associated with a reduction in glycogenolytic rate as a consequence of the reduced muscle glycogen stores immediately before the start of the end spurt.

We observed no changes in $RPE_{overall}$, despite the significant reduction in power output in the EP trial. This is in accordance with several lines of evidence suggesting that participants alter their pacing based on how they perceive their effort during the race [11,24]. Accordingly, Garcin et al. [13] have proposed that, as for RPE, the regulation of exercise intensity may utilize the estimated time limit as an important mediator of pacing strategy. Therefore, the process of controlling pacing takes into account both the amount of distance remaining to be covered and the momentary value of RPE. Indeed, it has previously been shown that, independently of the condition, athletes normally adopt an increase in RPE which is proportional to the exercise distance completed [12,24]. Even when unexpected and unfavourable premature metabolic disruption occurs, such as when hypoxic air is breathed in the middle of a trial, subjects rapidly decrease their power output to maintain the same RPE pattern over the course of a 5-km cycling time trial [24]. Similarly, Abbiss et al. [1] showed

that power output and muscle activation of the biceps femoris and soleus were reduced during a 100-km cycling time trial in a hot condition (34º) when compared a cold condition (10º), but RPE and pain intensity were not significantly different between trials, suggesting that participants adjusted their pacing to maintain similar values to RPE during the trial. It has been proposed that this is important to prevent premature disturbances in physiological systems and energetic reserves, and to be able to conclude the trial [34]. Thus, our results corroborate with these studies and suggest that when unfavourable conditions are present during the trial, the undesirable feelings cause participants to reduce their power output while maintaining the same RPE pattern over the course of a 200-kJ cycling time trial.

Another interesting result was that the RPE_{legs} increased at the same rate in both conditions. Participants submitted to an exercise-diet protocol designed to reduce CHO availability reported greater perception of tiredness in their legs during time-to-exhaustion exercise [27]. Although an increase in perceived muscle strain did not have a significant effect on long-duration, closed-loop exercise [22], probably because other factors such as core and skin temperature may be more important [28], it could be suggested that sensations of tiredness in the legs may have been important for the adjustment of pacing during our high-intensity cycling time-trial. Muscle strain has been hypothesised to play an important role in the overall perceived exertion generated during high-intensity exercise [20]. Therefore, participants in the present study could have changed their pacing during EP trial to prevent an excessive development of peripheral muscle fatigue [4].

Obviously, the validity of our results depends on the effectiveness of the muscle glycogen depletion protocol. We have utilized a previously validated protocol, which has been shown to significantly reduce muscle glycogen content to approximately 50 to 70% of pre-exercise values [14,15,19]. After the participants performed the muscle glycogen depletion protocol, they fasted (10-12 h of overnight fast) until the following morning, when they consumed a standardized breakfast contained only 10% of CHO one hour before the

EP trial. This procedure would have ensured that the muscle glycogen stores of the participants were significantly reduced in the EP condition. Finally, it should be noted that we used a sample composed by physically-active men, who were engaged in a regular exercise program that involved high-intensity cycling exercise, but who were not highly trained in any particular sport. Since trained cyclists perform frequently high-intensity exercises, further studies should investigate if reduction in the CHO availability alters also pacing strategy in high-level athletes.

In conclusion, the results of this study suggest that a reduction in the muscle glycogen content is associated with to a reduction in the duration of the fast-start, a discrete but significant reduction in power output during the middle of the trial, and a reduction in the magnitude of the end spurt, impairing the overall performance during a middle-duration cycle time-trial. The fact that RPE was almost the same in CON and EP suggests that pacing strategy is regulated in a responsive manner based on how the athletes perceive the effort at any moment during the race.

References

1. 1. Abbiss CR, Burnett A, Nosaka K, Green JP, Foster JK, Laursen PB. Effect of hot versus cold climates on power output, muscle activation, and perceived fatigue during a dynamic 100-km cycling trial. J Sports Sci 2010; 28: 117-125.
2. Abbiss CR, Laursen PB. Describing and understanding pacing strategies during athletic competition. Sports Med 2008; 38: 239-252.
3. Aisbett B, Le Rossignol P, McConell GK, Abbiss CR, Snow R. Effects of starting strategy on 5-min cycling time-trial performance. J Sports Sci 2009; 27: 1201-1209.
4. Amann M, Proctor LT, Sebranek JJ, Pegelow DF, Dempsey JA. Opioid-mediated muscle afferents inhibit central motor drive and limit peripheral muscle fatigue development in humans. J Physiol 2009; 587: 271-283.
5. Atkinson G, Peacock O, Gibson AS, Tucker R. Distribution of power output during cycling: impact and mechanisms. Sports Med 2007; 37: 647-667.

6. Bishop D, Bonetti D, Dawson B. The influence of pacing strategy on VO_2 and supramaximal kayak performance. Med Sci Sports Exerc 2002; 34: 1041-1047.
7. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982; 14: 377-381.
8. Bosch AN, Dennis SC, Noakes TD. Influence of carbohydrate loading on fuel substrate turnover and oxidation during prolonged exercise. J Appl Physiol 1993; 74: 1921-1927.
9. Cohen J (ed). Statistical power analysis for the behavioral sciences, Hillsdale: Lawrence Erlbaum, 1988: 572.
10. de Koning JJ, Bobbert MF, Foster C. Determination of optimal pacing strategy in track cycling with an energy flow model. J Sci Med Sport 1999; 2: 266-277.
11. de Koning JJ, Foster C, Bakkum A, Kloppenburg S, Thiel C, Joseph T, Cohen J, Porcari JP. Regulation of pacing strategy during athletic competition. PLoS One 20111;6: e15863.
12. 11. Faulkner J, Parfitt G, Eston R. The rating of perceived exertion during competitive running scales with time. Psychophysiology 2008; 45: 977-985.
13. Garcin M, Coquart J, Salleron J, Voy N, Matran R. Self-regulation of exercise intensity by estimated time limit scale. Eur J Appl Physiol 2012; 112: 2303-2312.
14. Gollnick PD, Armstrong RB, Sembrowich WL, Shepherd RE, Saltin B. Glycogen depletion pattern in human skeletal muscle fibers after heavy exercise. J Appl Physiol 1973; 34: 615-618.
15. Gollnick PD, Piehl K, Saltin B. Selective glycogen depletion pattern in human muscle fibres after exercise of varying intensity and at varying pedalling rates. J Physiol 1974; 241: 45-57.
16. Grisdale RK, Jacobs I, Cafarelli E. Relative effects of glycogen depletion and previous exercise on muscle force and endurance capacity. J Appl Physiol 1990; 69: 1276-1282.
17. Harriss DJ, Atkinson G. Update – Ethical Standards in Sport and Exercise Science Research. Int J Sports Med 2011; 32: 819-821.
18. Hargreaves M, McConell G, Proietto J. Influence of muscle glycogen on glycogenolysis and glucose uptake during exercise in humans. J Appl Physiol 1995; 78: 288-292.

19. Heigenhauser GJF, Sutton JR, Jones NL. Effect of glycogen depletion on the ventilatory response to exercise. J Appl Physiol 1983; 54: 470-474.
20. Hollander DB, Kilpatrick MW, Ramadan ZG, Reeves GV, Francois M, Blakeney A, Castracane VD, Kraemer RR. Load rather than contraction type influences rate of perceived exertion and pain. J Strength Cond Res 2008; 22: 1184-1193.
21. Hopkins WG. Measures of reliability in sports medicine and science. Sports Med 2000; 30: 1-15.
22. Johnson NA, Stannard SR, Chapman PG, Thompson MW. Effect of altered preexercise carbohydrate availability on selection and perception of effort during prolonged cycling. Eur J Appl Physiol 2006; 98: 62-70.
23. Jones AM, Wilkerson DP, Vanhatalo A, Burnley M. Influence of pacing strategy on O_2 uptake and exercise tolerance. Scand J Med Sci Sports 2008; 18: 615-626.
24. Joseph T, Johnson B, Battista RA, Wright G, Dodge C, Porcari JP, de Koning JJ, Foster C. Perception of fatigue during simulated competition. Med Sci Sports Exerc 2008; 40: 381-386.
25. Lima-Silva AE, Bertuzzi RC, Pires FO, Barros RV, Gagliardi JF, Hammond J, Kiss MA, Bishop DJ. Effect of performance level on pacing strategy during a 10-km running race. Eur J Appl Physiol 2010; 108: 1045-1053.
26. Lima-Silva AE, De-Oliveira FR, Nakamura FY, Gevaerd MS. Effect of carbohydrate availability on time to exhaustion in exercise performed at two different intensities. Braz J Med Biol Res 2009; 42: 404-412.
27. Lima-Silva AE, Pires FO, Bertuzzi RC, Lira FS, Casarini D, Kiss MA. Low carbohydrate diet affects the oxygen uptake on-kinetics and rating of perceived exertion in high intensity exercise. Psychophysiology 2011; 48: 277-284.
28. Nybo L, Nielsen B. Perceived exertion is associated with an altered brain activity during exercise with progressive hyperthermia. J Appl Physiol 2001; 91: 2017–2023.
29. Rauch HG, St Clair Gibson A, Lambert EV, Noakes TD. A signalling role for muscle glycogen in the regulation of pace during prolonged exercise. Br J Sports Med 2005; 39: 34–38.

30. Sabapathy S, Morris NR, Schneider DA. Ventilatory and gas-exchange responses to incremental exercise performed with reduced muscle glycogen content. J Sci Med Sport 2006; 9: 267-273.
31. Shearer J, Marchand I, Tarnopolsky MA, Dyck DJ, Graham TE. Pro- and macroglycogenolysis during repeated exercise: roles of glycogen content and phosphorylase activation. J Appl Physiol 2001; 90: 880-888.
32. Sherman WM, Costill DL, Fink WJ, Miller JM. Effect of exercise-diet manipulation on muscle glycogen and its subsequent utilization during performance. Int J Sports Med 1981; 2: 114-118.
33. Stone MR, Thomas K, Wilkinson M, St Clair Gibson A, Thompson KG. Consistency of perceptual and metabolic responses to a laboratory-based simulated 4,000-m cycling time trial. Eur J Appl Physiol 2011; 111: 1807-1813.
34. Tucker R. The anticipatory regulation of performance: The physiological basis for pacing strategies and the development of a perception-based model for exercise performance. Br J Sports Med 2009; 43: 392-400.
35. Vandenberghe K, Hespel P, Vanden Eynden B, Lysens R, Richter EA. No effect of glycogen level on glycogen metabolism during high intensity exercise. Med Sci Sports Exerc 1995; 27: 1278-1283.

Figure Legends:

Figure 1. A. Mean and standard error of the mean (SEM) for power output during the start (0-50 kJ), middle (between 50-175 kJ), finish (175-200 kJ), and the magnitude of the end spurt (power output at 175-200 kJ less power output at 150-175 kJ intervals) for the control condition (CON) and after an exercise protocol designed to decrease muscle glycogen levels (EP). *Significantly different; NS: not significant. **B.** Mean and standard error of the mean (SEM) for power output at the end of each 25-kJ interval during the 200-kJ time trial for the control and EP conditions. *Significantly higher than the EP for the same interval ($P < 0.05$).

†Significantly different than the 125-150 and 150-175 kJ interval ($P < 0.05$). ††Significantly different than all previous intervals, except the 0-25 kJ interval ($P < 0.05$).

Figure 2. Mean and standard error of the mean (SEM) for rating of perceived exertion (RPE) overall (**A**) and legs (**B**) at the end of each 25-kJ interval during the 200-kJ time trial for the control condition and after an exercise protocol designed to decrease muscle glycogen levels (EP). There was no difference between the conditions, but the RPE value in any given moment was higher than the prior values ($P < 0.05$).