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time trial**

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Complete List of Authors:	Costa, Vitor; Universidade do Estado de Santa Catarina Guglielmo, Luiz; Federal University of Santa Catarina, Sports Center Paton, Carl; Eastern Institute of Technology
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The effects of block training on pacing during 20-km cycling time trial

Vitor Pereira Costa, Luiz Guilherme Antonacci Guglielmo, Carl David Paton

Corresponding author:

Vitor Pereira Costa

Santa Catarina State University, Florianópolis, Santa Catarina Brazil. CEP: 88040-900

Phone: 55 (048) 3664-8600

Email: vitor.costa@udesc.br

Affiliation and address co-author:

Luiz Guilherme Antonacci Guglielmo

Federal University of Santa Catarina, Campus Universitário Trindade, Florianópolis, Santa Catarina Brazil. CEP: 88040-900

Phone: 55 (048) 3721-4774 □

Email: luiz.guilherme@ufsc.br

Carl David Paton

Eastern Institute of Technology, Health and Sport, Gloucester Street, Taradale, Napier 4114, New Zealand.

Phone: 06 974 8000 Extension 512

Email: cpaton@eit.ac.nz

Abstract

The aim of this study was to determine the effects of block training (BL) on pacing during a 20-km hilly cycling time trial (TT) in trained cyclists. Twenty male cyclists were separated into two groups: control and BL. The training of each cyclist was monitored during a period of 3 weeks. In the first week cyclists performed an overload period of seven consecutive days of high intensity interval training followed by two weeks of normal training. Cyclists performed one TT before intervention and two TT after seven and fourteen days at the end of training. Each training session consisted of 10 sets of 3 repeated maximal-effort sprints (15, 30, and 45s) with an effort/recovery duration ratio of 1:5. The main finding of this study was that the power output displayed a significantly higher start from the start until the halfway point of the TT ($p<0.05$). Additionally, power output was characterized by a significant higher end spurt in the final 2 km in the BL after two weeks at the end of training ($p<0.05$). In addition, after two weeks at the end of the overload period the distribution of cadence was significantly lower throughout the TT ($p<0.01$). Therefore, a short period of consecutive days of intense training enhances cycling performance and changes the power output in the beginning and final part of the TT in trained cyclists.

Key words: Cyclists, power output, pedal cadence, heart rate, time trial.

Introduction

Continuous and high intensity interval training (HIT) methods are frequently used in every phase of periodization to improve cycling performance (Laursen 2010). Continuous training is characterized by long durational efforts with constant low intensities. This method is frequently used during the basic phase of annual preparation to gradually improve cycling performances during the season (Paton and Hopkins 2004). Conversely, during the pre-competitive and competitive period of the season, cycling performance increases with the addition of intense training in the training programme (Paton and Hopkins 2004). HIT is performed by a combination of repetitive stimulus and a corresponding recovery period. There are several possibilities to alter intensity; duration, volume of the intervals as well as the recovery period in-between efforts. Recently, a review of the effects of HIT on cycling performance (Costa et al. 2014) classified HIT into three categories: sub-maximal (below maximal oxygen uptake (VO_{2max})), maximal ($\sim VO_{2max}$) and supra-maximal (above VO_{2max}). Irrespective of the type, the method has been regarded as one of the most efficient strategies to enhance cycling performance (2-4%) (Laursen and Jenkins 2002; Costa et al. 2014).

The majority of the studies suggest that the optimal frequency of the HIT to provide gains in cycling performance should be 6 to 12 training sessions over a period of successive weeks in trained cyclists (Paton and Hopkins 2004). More recently, some studies have been proposed to accumulate consecutive days (5 to 14 days) of HIT to rapidly enhance physiological indexes (Rodas et al. 2000; Breil et al. 2010; Rønnestad et al. 2012b), alpine sky performance (Breil et al. 2010) and cycling performance (Rønnestad et al. 2012b). Consecutive training stimuli typically results in a large physiological overload and possibly a drop in performance in the following days due to incomplete recovery between the sessions (Meeusen et al. 2013). When followed by an appropriate recovery period the block training (BL) results in super-compensation and raises the level of performance above the levels already achieved by the training that had been completed (Meeusen et al. 2013).

A common sports specific measurement in cycling performance is the time trial (TT) races. In a TT competition, cyclists race maximally against the clock completing a pre-established distance in the shortest time possible. The majority of TT events cover a distance of between 5 to 60 km and are performed individually, except in grand tour and velodrome events that include

team TT. As an individual sport, it has become important for the cyclists to determine their own pacing strategy for races. Pacing strategy starts prior to testing or from the beginning of exercise (Roelands et al. 2013). It is believed that sprint events (i.e. ≤ 15 -120 seconds) are performed in an 'all-out' strategy, while longer intervals (> 2 minutes) may include a variety of pacing profiles such as negative, all-out, positive, even, parabolic-shaped and variable pacing strategies (Abbis and Laursen 2008). Indeed, a pacing strategy can be influenced by a number of factors such as training, nutritional strategies, aerodynamics, level ground of the terrain, environmental conditions and psychology (Atkinson et al. 2007). The mathematical models of cycling performance reveal that athletes should vary the pacing in response to changes in environmental resistance (Boswell 2012; Swain 1997; Atkinson et al. 2007). Thus, it is important that cyclists select a variable pacing strategy to achieve optimal performance in cycling events when greater variations in environmental condition such as hilly or windy TT occur.

The pacing studies in cycling have attempted to focus on the effects of short strategies, reproducibility, ergogenic aids, and environmental conditions on flat TT performances (Renfree et al. 2012, Santos et al. 2013; Thomas et al. 2012). Studies investigating the effects of a short period of consecutive days of HIT on pacing, during hilly TT were not found and could provide important insights showing the possible performance enhancements over a task from the beginning through to the final point. In fact, to the best of our knowledge, we found only one study that reported enhancements ($\sim 7\%$) ($p = 0.006$ – 0.044) in pacing during the last three kilometres on a 10-km running TT after eight weeks of resistance training (Damasceno et al., 2015). Moreover, recent studies reported that BL enhance endurance performance with only a few training sessions that enable competitive athletes to achieve peak performance rapidly (Rønnestad et al. 2012). Therefore, the aim of this study was to determine the effects of BL on pacing during a 20-km hilly cycling TT in trained cyclists.

Material and methods

Subjects

Twenty trained male cyclists volunteered to participate in this study (Table 1). The cyclists had a minimum experience of two years in competitions and were training a minimum of 10 hours per week (~ 300 km per week). All cyclists were informed of the purpose and risks associated with

participation before giving their written informed consent to participate. The study was performed in accordance with ethical standards (Harris 2013). Also, the study was approved by the institutional research ethics committee in accordance with the declaration of Helsinki.

Study design

First, the cyclists reported to laboratory to have their anthropometric measures recorded to estimate the percentage of body fat according to Jackson and Pollock's three site formula: pectoral, abdomen and quadriceps (Jackson and Pollock 1978). Cyclists were randomly assigned to one of two conditions; control group (C; n = 10) and block-training group (BL; n = 10) (Table 1). The training of each cyclist in both groups was monitored for a period of 3 weeks in total. The first week the BL cyclists performed seven consecutive days of HIT followed by two weeks of normal training. 24 hours before the TT and training intervention, cyclists performed a graded exercise test (GXT) and a TT for familiarization. The study design included one TT before the HIT and two TT which were performed seven and fourteen days after the cyclists finished the HIT. The normal training weeks were based on previous studies in tapering that showed a period of approximately two weeks to be optimal to enhance performance after intense training (Hatle et al. 2014; Mujika 2010). The BL performed a flat tapering and was recommended to avoid high intense and high volume training during the normal training. The C completed two TT separated by three weeks, which they continued with their own personal training programmes different to the normal training of the BL group. The C group training included 1 or 2 sessions of HIT interspaced by moderate and light training sessions. Also, the C group cyclists were in the competitive period of their annual season training of approximately 10 to 12 hours per week. Also, the C group cyclists were in the competitive period of their annual season and they were allowed to keep their own racing schedule programs during the weekends.

All cyclists had previously participated in laboratory cycle ergometer testing and were familiar with general exercise testing procedures. In the 24 hours before any testing session, participants were instructed to avoid strenuous physical activity, any performance altering supplements and to replicate nutrition as closely as possible before each TT. Throughout all the tests, cooling was provided via two 30 cm pedestal fans and the ambient temperature of the laboratory was controlled at 20°C with a relative humidity level of 50-60%.

Graded exercise test

Cyclists completed GXT until volitional exhaustion to determine their maximal physiological parameters. The cycle ergometer was adjusted to replicate the participants' preferred racing position, which was recorded and replicated for the GXT. All tests were conducted on an electronically braked cycle ergometer (Velotron Dynafit Pro, RacerMate Inc, WA, USA). Cyclists performed a 15 min warm-up at a self-selected intensity followed by 5 min of rest. Thereafter, the GXT started at 100 W and the power output was increased at a rate of 40 W every 4 min until volitional exhaustion. The participants were instructed to maintain their preferred cadence. The criteria to terminate the test was set when the cyclist could not maintain the preferred cadence for more than 10 seconds during the final stage of the test. If the final stage of the exercise test was not completed, the peak power output (PPO) was calculated using the equation of Kuipers et al. (1985):

$$\text{PPO} = \text{Pf} + (t/240 \times 40)$$

Pf was the last completed workload, t is the time in seconds of the uncompleted workload, 240 is the time of each stage in s, and 40 is the workload augments in each stage. The expired respiratory gases were collected into metabolic Metamax 3B system (Cortex, Leipzig, Germany). Prior to each test, the system was calibrated in accordance with manufacturers instructions using known alpha gas standards. $\text{VO}_{2\text{max}}$ was defined as the highest oxygen uptake (VO_2) over a 30 s value recorded during the test. During the final 30 seconds of each stage 25 μL of blood was collected from the participant's fingertip and immediately analysed for whole blood lactate concentration using an automated system (YSI 1500, Yellow Springs, OH, USA) calibrated to the manufacturer's specifications. The onset of blood lactate accumulation (OBLA) was determined as the power output at which blood lactate reached a concentration of 4 mmol l^{-1} (Sjödín et al. 1982).

20-km hilly time trial

Cyclists completed the variable graded cycling 20-km TT using the same cycle ergometer as previously used in the GXT. The TT course profile (Figure 1) was recently investigated in a group of competitive cyclists and showed lower coefficient of variation from mean power output and final time (2% and 1%, respectively) (Clark et al. 2014). Cyclists initially completed a 20

minute standardised warm up consisting of three repeated increasing intensity bouts. The first two minutes were completed at $2\text{--}2.5\text{ W}\cdot\text{kg}^{-1}$, followed by two minutes at $3\text{--}3.5\text{ W}\cdot\text{kg}^{-1}$ and finally one minute at $4\text{--}4.5\text{ W}\cdot\text{kg}^{-1}$ and repeated consecutively. For the final five minutes cyclists pedalled at a fixed intensity of 100 W . Thereafter, a 20-km self-paced maximal TT was performed. Cyclists were able to view their progress over the course, distance and gear selection; all other information was blinded to remove any potential pacing effect. Furthermore, no verbal encouragement was provided. Cyclists were recommended to complete each TT in a self-selected pacing as fast as possible with no restriction on gear selection, cadence or cycling posture. Throughout the TT participants were able to consume water *ad libitum*. Power output, cadence and heart rate were recorded during the TT by the cycle ergometer.

XXX Figure 1 XXX

Training

The BL cyclists completed seven consecutive days of HIT. The total training session time was ~ 120 minutes including ~ 15 minutes of accumulated HIT, 75 minutes of recovery period, and 15 minutes of warm up and cool down for each period. The warm up and cool down were performed in self-selected intensity $<150\text{ W}$. Cyclists completed 10 sets of maximal sprints lasting 15, 30 and 45 s and the work to rest ratio was 1:5. The sprints were performed at maximal effort and recovery intervals at a self-selected intensity below 30–40% of maximal aerobic power as a form of active recovery. The first, fourth and seventh training session was performed indoors using the laboratory cycle ergometer previously described. Participants completed each indoor sprint sessions under the supervision of a researcher to ensure the sprints were adhered to as stringently as possible. The cyclists used their own bicycle on the road when performing the remaining training sessions. Power output during all training sessions were controlled and registered using the PowerCal device. Recent studies reported that PowerCal device is unreliable and not valid to measure power output during cycling sprints and TT (Costa et al. 2015; Costa et al. 2016). Therefore, we did not use PowerCal data for the analysis in the study. Moreover, cyclists used a pre-recorded audio signal that indicated the time for sprint and recovery periods.

Statistical analysis

Simple descriptive statistics are shown as means $\pm$ between-subject standard deviations. Data from the study were analyzed using both significance, and magnitude based inferential approaches. Significance based analyses were performed using SPSS statistical software, version 20 for Windows (SPSS Inc, Chicago, IL) with alpha set at 0.05. Initially, the characteristics of the C group and BL group were compared using a t-test. Also, the C group TT1 and TT2 average indexes were compared using a t-test. The BL group TT, TT1 and TT2 average scores were compared using a one-way analysis of variance with repeated measures. The distribution of power output, cadence and HR over the TT in each group was compared using a two-way analysis of variance with repeated measures, with factors training (pre and post) and distance over the time TT (every 2-km). When necessary, subsequent post-hoc comparisons were made using Bonferroni corrections. In addition, the percentage of change in power output, cadence and HR over the TT between the groups were compared using two way anova with repeated measures with post-hoc comparisons using the Bonferroni test. In the magnitude based approach, the mean effects of training and their confidence limits were estimated with a ready-made for purpose spreadsheet (Hopkins, 2006) which utilizes the unequal-variances t statistic to perform between group comparisons. Group wise comparisons were computed for change scores between the mean values of the pre-test (TT) and each of the two post-tests (TT1 and TT2) in the BL training group and between the pre (TT1) and post-test (TT2) in C group. Each subject's change scores between the trials was expressed as a percent of the baseline score via analysis of log-transformed values. Data were log-transformed in order to reduce bias arising from any non-uniformity of error in the data. The spreadsheet also computes chances that the true effects are substantial, when a value for the smallest worthwhile change is entered. We used a value of 1% for the performance power measures, as previous research has shown that this value represents the smallest worthwhile enhancement in power for cyclists competing in TT events (Paton and Hopkins 2006). To date no research has established how percentage changes in physiological measures would translate directly to percent changes in cycling performance, therefore we interpreted changes in our physiological measures using default standardized effects (the change in mean divided by the between subject standard deviation). The magnitudes of the standardised effects for the testing measures were also interpreted and reported using the established effect size (ES) thresholds of:

0.2, 0.5, and 0.8 for small, moderate, and large effects respectively in accordance with the recommendations of Cohen (1996). ES values <0.2 were deemed trivial differences and considered to be not worthwhile.

Results

Table 1 shows the characteristics of the cyclists in both groups. There was a significant difference between the groups in [La]max ($9.7 \pm 1.8 \text{ mmol.l}^{-1}$ vs. $8.4 \pm 1.1 \text{ mmol.l}^{-1}$; $p= 0.04$) for the C group and BL group, respectively. In addition, large ES was found -0.90 between the groups.

XXX Table 1 XXX

Table 2 shows that there were no significant differences in all measures of the TT of the C group. Also, we found trivial ES for the majority of the variables. Furthermore, Table 2 shows the comparisons between the TT before and after training intervention for the BL group. The cyclists reported a large to a very large decrease in final time and cadence after one and two weeks of the overload period, respectively. Also, the final time and cadence ES were moderate to high after cyclists finished the one and two weeks of training. Mean power output demonstrated a moderate to high increase after the one and two weeks of the post overload period. The mean power output ES was also moderate to high. The HR values did not change significantly before and after training intervention. In addition, we did not find any significant enhancements in performance indexes and cadence in the post training period.

XXX Table 2 XXX

Table 3 shows the relative change score (as a percentage) for all measured variables during the performance tests between the groups. There were large (ES - 0.68–0.91) gains in performance measures for the BL relative to the control condition.

XXX Table 3 XXX

For the C group the two way anova with repeated measures showed significant interaction between the factors training vs. distance for power output ($f= 26.7$; $p< 0.0001$); cadence ($f= 26.2$; $p< 0.0001$); and HR measures ($f= 7.9$; $p= 0.03$). There were no significant differences in power output, cadence and HR between TT1 and TT2 over each two kilometre in the C group (Figure 2A, 2B, 2C, $p> 0.05$).

XXX Figure 2 XXX

For the BL group the two way anova with repeated measures showed significant interaction between the factors training vs. distance for power output ($f= 23.3$; $p< 0.0001$); cadence ($f= 27.1$; $p< 0.0001$); and HR measures ($f= 6.7$; $p= 0.02$). After one-week of training intervention, the magnitude of the augments of power output during each two kilometre of the TT was significantly higher in the beginning and through to the halfway point of the event, kilometre 16 and 20 (Figure 3A; $p= 0.05$ to 0.0003). The effects of training on distribution of power output were slightly higher after two-weeks at the end of the training (Figure 3A; $p= 0.01$ to 0.0001); however, we did not find any significant differences between the TT post training ($p= 0.44$ to 0.08).

After one-week of training intervention, cadence decreased at each two kilometre of the TT, except in the kilometre 16 (Figure 3B; $p< 0.05$). Cadence was significantly lower after two weeks at the end of training (TT2) compared to the TT and TT1 (Figure 3B; $p< 0.01$; $p< 0.05$, respectively). Cadence was also significant different between TT1 and Post-TT from the beginning of the trial to kilometre 8. HR did not change significantly during the TT irrespective of training (Figure 3C; $p> 0.05$).

XXX Figure 3 XXX

Figure 4 shows the percentage change (pre and post training) in power output, cadence and HR during the TT in both groups. For the BL group the two way anova with repeated measures showed significant interaction between the groups vs. distance for power output ($f= 19.1$; $p< 0.001$); cadence ($f= 22.7$; $p< 0.001$); and HR measures ($f= 8.2$; $p= 0.01$). It was observed that the

percentage change for power output and cadence was significantly higher and lower for BL group than C group over the entire course, respectively ($p=0.003$ – 0.039). In turn, no statistical differences were observed between the HR response before and after training for both groups ($p=0.193$ – 0.942).

XXX Figure 4 XXX

Discussion

The aim of this study was to investigate the effects of a short period of HIT on pacing during a 20-km hilly cycling TT. To the best of our knowledge, this is the first study that attempted to verify the effects of a training intervention on pacing during a hilly TT. The main finding shows that the power output displayed a significantly higher start from the beginning to the halfway point of the TT after one and two weeks at the end of the overload period. In addition, the power output was characterized by a significantly higher end spurt in the final 2 km after a short period of cumulative intense training.

The pacing profiles have a variety of shapes during different exercise tasks and conditions (Atkinson et al. 2007). In a recent review (Abbis and Laursen 2008), such profiles were classified in negative, positive, even, all-out, parabolic (i.e. U, J or reverse J-shaped), and variable pacing strategies. It is believed that a curved parabolic (i.e. strong and rapid start, the middle portion slower and the final sprint) is commonly described in many types of events from a duration of 2 min to hours (Roelands et al. 2013). In the present study, the power distribution over the tests was characterized by a parabolic shape regardless the groups and performance gains. After training, cyclists still displayed a steeper parabolic shape with higher power distribution over the self-selected performance test. Indeed, power output was significantly higher from the beginning of the TT throughout the first 10 kilometres after the intervention. Moreover, power output was statistically higher on the kilometre 16 and in the final meters of the post-TT. In contrast, the C group did not change their power distribution substantially between the tests. The TT chosen was not flat and was based upon numerous changes in the gradient represented by both ascents and descents (Clark et al. 2014). We found a drop in the power output characterized by the long descent section of the TT (from km 12 to 14) regardless of both intervention and group. The

decrease in the power output was due to the resistive forces on the flywheel of the cycle ergometer simulating the downhill phase of the course profile (Clark et al. 2014). The accentuated end spurt in the final meters showed a higher power output after a short period of intense training. The higher end spurt phenomenon increased the considered reserve of the cyclists maintains for the majority of the TT in order to reduce the hazard of catastrophic collapse (Roelands et al. 2013). Thomas et al. (2012) also reported a parabolic shape (i.e. U-shape) power distribution between the three 20-km flat TT tests. However, the authors found high levels of variability in the power output during the first kilometre between the self-paced 20-km TT compared to the low degree of variability in power output for most of the remainder of the distance between the trials. Also, the authors reported that cyclists increased the power output in the final kilometre of the TT. Indeed, it's possibly some level of variability in the power output between the trials in our study, even previous studies showed a high level of reliability in the 20-km hilly TT used in our study (Clark et al. 2014).

A likely reason for the changes in performance and consequently on distribution of power is probably due to the adaptations of the training rather than any potential effects of pacing strategy (i.e. fast, even, low start) since cyclists were instructed to perform a self-selected maximal TT in both groups. To the best of our knowledge, we found one study regarding the effects of training intervention on pacing during running (Damasceno et al. 2015). Damasceno et al. (2015) reported the effects of weight strength training on neuromuscular adaptations and on pacing during a 10-km running performance. The authors found that the addition of eight weeks of explosive leg strength training on running normal training improved running performance by 2.5%. In addition, the running performance improved mainly due to the end spurt achieved in the last 2800 m of the 10-km running trial. Therefore, heavy strength training improved the neuromuscular characteristics of endurance runners, resulting in changes in pacing with a faster and more-sustained end-spurt during a 10-km running TT.

Damasceno et al., (2015) reported that the changes in pacing during a 10-km TT was not accompanied by an alteration in the rating of perceived exertion (RPE), indicating that athletes were able to maintain higher speeds with similar RPE after strength training period. Indeed, previous studies proposed that the RPE is generated as a result of the numerous afferent signals during exercise and acts as a mediator of subsequent alterations in skeletal muscle activation (De

Morree et al. 2012). Thus, the RPE represents the integration of the alterations in physiological systems during dynamic exercise and could be related as a primary regulator of pacing strategy (Tucker and Noakes, 2009). In our study, unfortunately we missed the RPE and we can not confirm if the changes in pacing strategy induced by training may have allowed the cyclists to exercise at a greater intensity for the same level of perceived exertion. These would support the notion that neuromuscular mechanisms related to peripheral fatigue are some of the possible variables utilized by central nervous system to regulate exercise intensity, particularly during the beginning and final phase of a cycling time trial.

The basis of the training programme used in our study included the method of training (i.e. HIT) and type of periodization (i.e. block training). The effects of HIT suggested that the main physiological adaptations occurred by increasing the concentration of energetic stores (i.e. glycogen), activities of anaerobic-aerobic enzymes, buffer capacity and recruitment of type II muscular fibers (Jacobs et al. 1987; Laursen and Jenkins 2002; Creer et al. 2004). Also, HIT has been found to improve lactate thresholds, VO_{2max} , PPO and economy in cyclists and non-cyclists. Block training periodization is referred to as a training cycle of highly concentrated specialized workloads. In cycling, the block training can be performed using high volume/low intensity (i.e. continuous exercise) or low volume/high intensity (i.e. HIT). Indeed, the concentrated period of training had an impact on physiological systems due to the cumulative and residual effects of the intervention. These concepts are strongly related to the “ideal” dose of training called “functional overreaching” instead of deleterious overtraining. However, the physiological adaptations from consecutive days of training are not well understood. A recent study, reported larger improvements on VO_{2max} (8.8%) in a group of trained cyclists after 12 weeks of BL periodization (Rønnestad et al. 2012b). Furthermore, the authors found that even in endurance-trained individuals, a concentrated period of HIT may increase lactate threshold (22.0%), hemoglobin mass (5.6%) and gross efficiency (2.9%) (Rønnestad et al. 2012b). This is in accordance with the increase in VO_{2max} (6.0%) and lactate threshold (9.6%) found in response to an 11-day of HIT in alpine skiers (Breil et al. 2010). Collectively, the enhancements in physiological variables associated with endurance performance (i.e. VO_{2max} , lactate thresholds, and economy) (Joyner and Coyle 2008) shown in our and previous studies support the changes that we found in the distribution of power output during the cycling TT post-intervention.

A second find of the present study was that mean free chosen cadence during the TT was significantly lower to post-training (88 ± 6 RPM) compared to the TT pre-training (94 ± 9 RPM). Furthermore, the distribution of cadence during the TT was significantly lower at each kilometre after the training intervention. The majority of studies investigating the effects of training in cycling cadence have focused on adaptations from strength training instead of the effects of HIT. Indeed, when cyclists pedal at low cadences the muscle force applied to the cranks increase (Bertucci et al. 2005). Rønnestad et al. (2012a) reported that freely chosen cadence during a constant 5-min cycling at 125W reduced by 11 ± 2 rpm from pre strength training intervention to 4 weeks into the intervention period in non-cyclists. Conversely, well-trained cyclists did not change their freely chosen cadence after the addition of strength training in the cycling training program even though they improved 1 RM test. Given the short period of strength training related in the later study (i.e. 4 weeks), it is expected that greater adaptations in the first phase of strength training can occur in the nervous system rather than in muscular fibers. The strength training adaptations suggests that the reduction in the inhibitory feedback from mechanoreceptors and Golgi tendon organs could be related to an increase in strength and consequently a decrease in the freely chosen cadence (Rønnestad et al. 2012a). Cycling using “all out” HIT is a complex movement and it is likely that the neural adaptations also occur after a short period of concentrated sprint training (Creer et al. 2004). Ross et al. (2001) suggested potential neural mechanisms influenced by sprint performance including changes in temporal sequencing of muscle activation for more efficient movement, preferential recruitment of the fastest motor units, higher muscle innervations, and increased ability to maintain muscle recruitment and rapid firing for the duration of the sprint activity. Indeed, it is not well understood if these adaptations above are well established after cycling sprint training. Also, to generate and sustain higher forces during sprint training, the muscles use an additional recruitment of type II fibers (Jacobs et al. 1987). Collectively, the neuromuscular adaptations after a short period of HIT probably increased the capability of the cyclists to produce more force resulting in less cadence and consequently higher power output over the course during the TT.

Conclusion

In conclusion, our results suggest that a short period of HIT provide substantial positive effects during a self-paced computer-simulated variable graded cycling TT. Furthermore, the training intervention demonstrated that the cyclists displayed a higher power output during the first half of the task and a higher end spurt while the cadence was lower over the cycling TT compared to the baseline period. Also, the time course of distribution of power output showed that the main augments were after one week at the end of overload period with non-significant enhancements in the following week. Analysing the course profile before and after the training intervention could provide important insights into showing the possible performance enhancements over a task from the beginning through to the end point. The feedback from the pacing can inform the cyclist of the exact moment where the training would be the most effective. This study gives an opportunity for coaches to include a short-term of HIT in the cyclists training program for rapid improvements in the pacing profile and consequently on the performance during a variable graded cycling TT. In addition, cyclists could use the high intensity BL for the main races during the competitive annual season.

Conflicts of interest

The authors state that there are no personal conflicts of interest in the present study.

References

- Abbiss, C.R., and Laursen, P.B. 2008. Describing and understanding pacing strategies during athletic competition. *Sports Med.* **38**(3): 239-252. PMID: 18278984.
- Atkinson, G., Peacock, O., St Clair Gibson, A., and Tucker, R. 2007. Distribution of power output during cycling. Impact and mechanisms. *Sports Med.* **37**(8): 647-667. PMID: 17645369.
- Bertucci, W., Grappe, F., Girard, A., Betik, A., and Rouillon, J.D. 2005. Effects on the crank torque profile when changing pedalling cadence in level ground and uphill road cycling. *J. Biomech.* **38**(5): 1003-1010. PMID: 15797582.
- Boswell, G.P. 2012. Power variation strategies for cycling time trials: a differential equation model. *J. Sports Sci.* **30**(7): 651-9. doi: 10.1080/02640414.2012.654397.
- Breil, F.A., Weber, S.N., Koller, S., Hoppeler, H., and Vogt, M. 2010. Block training

- periodization in alpine skiing: effects of 11-day HIT on VO₂max and performance. *Eur. J. Appl. Physiol.* **109**(6): 1077-1086. doi: 10.1007/s00421-010-1455-1.
- Clark, B., Paton, C.D., and O'Brien, B.J. 2014. The reliability of performance during computer-simulated varying gradient cycling time trials. *J. Sci. Cycling.* **3**(3): 29-33. Available from <https://doaj.org/toc/2254-7053/3>.
- Cohen, J. 1996. Statistical power analysis for the behavioral sciences. New Jersey: Lawrence Erlbaum.
- Costa, V.P., Lucas, R.D., Souza, K.M., and Guglielmo, L.G.A. 2014. Efeitos do treinamento intervalado em variáveis fisiológicas e na performance de ciclistas competitivos. *Rev. Andal. Med. Deporte.* **7**(2): 83-9. doi:10.1016/S1888-7546(14)70067-X.
- Costa, V.P., Guglielmo, L.G., and Paton, C.D. 2015. Reproducibility and validity of the PowerCal device for estimating power output during sprints in well-trained cyclists. *Isok. Exerc. Sci.* **23**(2):127-132. doi: 10.3233/IES-150573.
- Costa, V.P., Guglielmo, L.G., and Paton, C.D. 2016. Validity and reliability of the PowerCal device for estimating power output during cycling time trials. *J. Strength Cond. Res.* **4**(21): [Epub ahead of print]. doi: 10.1519/JSC.0000000000001466.
- Creer, A.R., Ricard, M.D., Conlee, R.K., Hoyt, G.L., and Parcell, A.C. 2004. Neural, metabolic, and performance adaptations to four weeks of high intensity sprint-interval training in trained cyclists. *Int. J. Sports Med.* **25**(2): 92-98. PMID: 14986190.
- Damasceno, M.V., Lima-Silva, A.E., Pasqua, L.A., Tricoli, V., Duarte, M., Bishop, D.J., and Bertuzzi, R. 2015. Effects of resistance training on neuromuscular characteristics and pacing during 10-km running time trial. *Eur. J. Appl. Physiol.* **115**(7): 1513-22. doi: 10.1007/s00421-015-3130-z.
- De Morree, H.M., Klein, C., and Marcora, S.M. 2012. Perception of effort reflects central motor command during movement execution. *Psychophysiology.* **49**(9):1242-1253. doi: 10.1111/j.1469-8986.2012.01399.x.
- Harriss, D.J., and Atkinson, G. 2013. Ethical Standards in Sport and Exercise Science Research: 2014 Update. *Int. J. Sports Med.* **34**(12): 1025-1028. doi: 10.1055/s-0033-1358756.
- Hatle, H., Støbakk, P.K., Mølmen, H.E., Brønstad, E., Tjønnå, A.E., Steinshamn, S., Skogvoll, E., Wisløff, U., Ingul, C.B., and Rognmo, Ø. 2014. Effect of 24 sessions of high-

intensity aerobic interval training carried out at either high or moderate frequency, a randomized trial. *PLoS One*. **9**(2): e88375. doi: 10.1371/journal.pone.0088375.

Hopkins, W.G. 2006. Spreadsheets for analysis of controlled trials with adjustment for a predictor. *Sportscience*. **10**: 46–50. Available: <http://www.sportsci.org/2006/wghcontrial.htm>.

Jackson AS, and Pollock ML. 1978. Generalized equations for predicting body density of men. *Br. J. Nutr.* **40**(3):497-504. PMID: 718832.

Jacobs, I., Esbjornsson, M., Sylven, C., Holm, I., and Jansson, E. 1987. Sprint training effects on muscle myoglobin, enzymes, fiber types, and blood lactate. *Med. Sci. Sports Exerc.* **19**(4): 368-374. PMID: 2958671.

Joyner, M.J, and Coyle, E.F. 2008. Endurance exercise performance: the physiology of champions. *J. Physiol.* **586**(1): 35-44. PMID: 17901124.

Kuipers, H., Verstappen, F.T., Keizer, H.A., Geurten, P., and Van Kranenburg, G. 1985. Variability of aerobic performance in the laboratory and its physiologic correlates. *Int. J. Sports Med.* **6**(4):197-201. PMID: 4044103.

Laursen, P.B. 2010. Training for intense exercise performance: high-intensity or high-volume training? *Scand. J. Med. Sci. Sports*. **20**(2): 1-10. doi: 10.1111/j.1600-0838.2010.01184.x.

Laursen, P.B, and Jenkins, D.G. 2002. The scientific basis for high-intensity interval training optimizing training programs and maximizing performance in highly trained endurance athletes. *Sports Med.* **23**(1): 53-73. PMID: 11772161.

Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., Raglin, J., Rietjens, G., Steinacker, J., and Urhausen, A. European College of Sport Science; American College of Sports Medicine. 2013. Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med. Sci. Sports Exerc.* **45**(1): 186-205. doi: 10.1249/MSS.0b013e318279a10a.

Mujika, I. Intense training: the key to optimal performance before and during the taper. *Scand. J. Med. Sci. Sports* 2010. **20**(2): 24-31. doi: 10.1111/j.1600-0838.2010.01189.x.

Paton, C.D., and Hopkins, W.G. 2004. Effects of high-intensity training on performance and physiology of endurance athletes. *Sportscience*. **8**: 25-40.

Paton, C.D., and Hopkins, W.G. 2006. Variation in performance of elite cyclists from race to

- race. *Eur. J. Sport Sci.* **6**(1): 25–31. doi: 10.1080/17461390500422796.
- Renfree, A., West, J., Corbett, M., Rhoden, C., and St Clair Gibson, A. 2012. Complex interplay between determinants of pacing and performance during 20-km cycle time trials. *Int. J. Sports Physiol. Perf.* **7**(2): 121-129. PMID: 22173069.
- Rodas, G., Ventura, J.L., Cadefau, J.A., Cussó, R., and Parra, J. 2000. A short training programme for the rapid improvement of both aerobic and anaerobic metabolism. *Eur. J. Appl. Physiol.* **82**(5-6): 480-6. PMID: 10985604.
- Roelands, B., De Koning, J., Foster, C., Hettinga, F., and Meeusen, R. 2013. Neurophysiological determinants of theoretical concepts and mechanisms involved in pacing. *Sports Med.* **43**(5): 301-311. doi: 10.1007/s40279-013-0030-4.
- Rønnestad, B.R., Hansen, E.A., and Raastad, T. 2012a. Strength training affects tendon cross-sectional area and freely chosen cadence differently in noncyclists and well-trained cyclists. *J. Strength Cond. Res.* 2012. **26**(1): 158-66. doi: 10.1519/JSC.0b013e318218dd94.
- Rønnestad, B.R., Ellefsen, S., Nygaard, H., Zacharoff, E.E., Vikmoen, O., Hansen, J., and Hallén, J. 2012b. Effects of 12 weeks of block periodization on performance and performance indices in well-trained cyclists. *Scand. J. Med. Sci. Sports.* **24**(2): 327-335. doi: 10.1111/sms.12016.
- Ross, A., Leveritt, M., and Riek, S. 2001. Neural influences on sprint running: training adaptations and acute responses. *Sports Med.* **31**(6): 409-25. PMID: 11394561.
- Tucker, R., and Noakes, T.D. 2009. 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.* **43**(6):392–400. doi: 10.1136/bjsm.2008.050799. Epub 2009 Feb 17.
- Santos, R.A., Kiss, M.A., Silva-Cavalcante, M.D., Correia-Oliveira, C.R., Bertuzzi, R., Bishop, D.J., and Lima-Silva, A.E. 2013. Caffeine alters anaerobic distribution and pacing during a 4000-m cycling time trial. *PLoS One.* **8**(9): e75399. doi: 10.1371/journal.pone.0075399.
- Sjödin, B., Jacobs, I., Svedenhag, J. 1982. Changes in onset of blood lactate accumulation (OBLA) and muscle enzymes after training at OBLA. *Eur. J. Appl. Physiol. Occup. Physiol.* **49**(1): 45-57. PMID: 6213407.

Swain, D.P. 1997. A model for optimizing cycling performance by varying power on hills and in wind. *Med. Sci. Sports Exerc.* **29**(8): 1104-8. PMID: 9268969.

Thomas, K., Stone, M.R., Thompson, K.G., St Clair Gibson, A., and Ansley, L. 2012. Reproducibility of pacing strategy during simulated 20-km cycling time trials in well-trained cyclists. *Eur. J. Appl. Physiol.* **112**(1): 223-229. doi: 10.1007/s00421-011-1974-4.

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Table 1. Characteristics of the participants.

Variables	Control group	Block training group	<i>p</i> value	ES
Age (years)	36.2 ± 8.9	33.2 ± 10.9	0.26	-0.30
Weight (kg)	76.6 ± 8.7	74.8 ± 6.0	0.26	-0.24
Height (cm)	177 ± 5.8	177 ± 4.9	0.45	0.00
Fat (%)	12.8 ± 5.9	11.8 ± 6.3	0.38	-0.16
PPO (watts)	338 ± 48	335 ± 27	0.44	-0.08
VO ₂ max (L.min ⁻¹)	4.7 ± 0.6	4.6 ± 0.5	0.15	-0.18
VO ₂ max (ml.kg ⁻¹ .min ⁻¹)	61.6 ± 10.4	61.4 ± 5.1	0.18	-0.03
HRmax (bpm)	183 ± 6	180 ± 9	0.27	-0.40
[La]max (mmol.l ⁻¹)	9.7 ± 1.8	8.4 ± 1.1*	0.04	-0.90
OBLA (watts)	297 ± 38	293 ± 33	0.38	-0.11
OBLA (bpm)	167 ± 6	165 ± 7	0.30	-0.31

PPO: peak power output; VO₂max: maximal oxygen uptake; HRmax: maximal heart rate; [La]max: maximal blood lactate concentration; OBLA: onset blood lactate accumulation; ES: Effect size. * *p* < 0.05

Table 2. Measures of the time trial test in the control and block training groups.

	Control group				Block training group								
	TT				TT			TT – TT1		TT – TT2		TT1 – TT2	
	TT1	TT2	ES	<i>p</i> value	TT	TT1	TT2	ES	<i>p</i> value	ES	<i>p</i> value	ES	<i>p</i> value
Time	37.7 ±	38.0 ±	0.09	0.06	38.4 ±	37.4 ±	36.8 ±	-0.45	0.03	-0.78	0.002	-0.31	0.07
(min)	3.3	3.4			2.2	2.1*	1.8**						
PO (W)	292 ± 41	287 ± 38	-0.13	0.06	277 ± 26	288 ± 28*	296 ± 25**	0.41	0.04	0.75	0.003	0.30	0.07
RPM	91 ± 8	89 ± 9	-0.24	0.12	94 ± 9	90 ± 5*	88 ± 5**	-0.57	0.03	-0.86	0.01	-0.40	0.06
HR (bpm)	166 ± 11	164 ± 12	-0.17	0.08	166 ± 8	168 ± 10	168 ± 10	0.23	0.16	0.22	0.16	0.00	0.47

PO: power output; RPM: revolutions per minute; HR: heart rate; TT: time trial; ES: Effect size. * $p < 0.05$; ** $p < 0.01$.

Table 3. Comparison of changes in performance measures as percents between the groups.

	Time	Power output	Cadence	Heart rate
BLTT1 – C	- 3.4 ± 2.2	5.7 ± 2.6	2.0 ± 2.1	2.4 ± 2.2
% Difference (ES)	(- 0.68)	(0.69)	(- 0.38)	(0.28)
BLTT2 – C	- 5.0 ± 2.8	8.6 ± 3.2	4.2 ± 2.6	2.4 ± 2.2
% Difference (ES)	(- 0.85)	(0.91)	(-0.59)	(0.28)

BL: Block training; TT: time trial; ES: Effect size

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Figure 1. The computer simulated course showing the profile of the varying gradient time trial used in the study.

Figure 2. Power output (A), cadence (B) and heart rate (C) distribution during 20-km cycling hilly TT of the control group.

Figure 3. Power output (A), cadence (B) and heart rate (C) distribution during 20-km cycling hilly TT of the block training group. ^a Significantly different from control group ($p < 0.01$). ^b Significantly different from control group ($p < 0.05$). ^c Significantly different from control group and TT2 ($p < 0.05$).

Figure 4. Percentual changes between groups after training on the distribution of power output (A), cadence (B) and heart rate (C). ^a Significantly different from control group ($p < 0.01$). ^b Significantly different from control group ($p < 0.05$).

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172x74mm (300 x 300 DPI)

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111x235mm (300 x 300 DPI)

111x239mm (300 x 300 DPI)

105x232mm (300 x 300 DPI)