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ORIGINAL ARTICLE

Effect of cycling specialization on effort and physiological responses to uphill and flat cycling at similar intensity

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Abstract
Power output is considered one of the best tools to control external loads in cycling, but the relationship between a target power output and the physiological responses may suffer from the effects of road gradient, which is also affected by cyclist specialization. The objective was to determine the effects of cyclist specialization on effort perception and physiological response (heart rate and lactate concentration) while sustaining efforts at similar power output but riding on two different road gradients. Nineteen male competitive road cyclists performed two randomized trials of 10 min at 0% (velodrome) and 10 min at 6% road gradient (field uphill), at an intensity of 10% ± 3% below the individual's functional threshold power. Cadence was kept between 75 and 80 rpm in both trials and posture remained unchanged during the tests. Heart rate, speed, cadence, power output, blood lactate, and rate of perceived effort were measured for each trial. *K*-means cluster analyses differentiate uphill (n = 10) and flat specialists (n = 9) according to lactate responses. Flat specialists presented lower heart rate ($p < 0.001$ and ES = 0.2), perceived exertion ($p < 0.01$ and ES = 0.7), and blood lactate concentration ($p < 0.001$ and ES = 0.7) riding on the flat than uphill. Uphill specialists presented lower perceived exertion ($p < 0.01$ and ES = 0.8) and blood lactate concentration ($p < 0.01$ and ES = 0.5) riding uphill than on the flat. In conclusion, the combination of cyclist specialization and road gradient affects physiological and effort perception parameters in response to a similar power output demand. These factors deserve attention in training schedules and monitoring performance using power output data.

Keywords: *Physical training, bicycle, external load, pedalling, workload*

Highlights

- *K*-means cluster analyses differentiate uphill and flat specialists according to lactate responses during riding on two different road gradients.
- Flat specialists presented lower heart rate, perceived exertion and blood lactate concentration riding on the flat than uphill.
- Climb specialists presented lower perceived exertion and blood lactate concentration riding uphill than on the flat.
- Results suggest that the control of training load, performance prediction and scientific research, based on power output, may need to consider the road gradient and the cyclist specialization due to its effect on effort perception and physiological response.

Introduction

Mobile power metres are easy-to-use tools for measuring power output during outdoor cycling (Passfield, Hopker, Jobson, Friel, & Zabala, 2017; Schneeweiss, Haerlen, Ahrend, Niess, & Krauss, 2018). Power output data helps to better monitor external loads and its influence on physiological responses, helping to improve training schedule as well as to monitor performance, plan race strategies, monitor risks of injury, and prevent non-functional overreaching (Halson, 2014; Mujika, 2017). The field application of mobile power metres has grown rapidly in recent years, but research on the factors influencing power metrics during field conditions

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still require further in-depth study aimed at improving data interpretation (Passfield et al., 2017).

Several factors can influence power output responses during outdoor measures. Among the factors with recognized effect on power output are pedalling cadence (Chavarren & Calbet, 1999; MacIntosh, Neptune, & Horton, 2000), body position (e.g. seated vs standing) (Costes, Turpin, Villeger, Moretto, & Watier, 2018), dehydration (Logan-Sprenger, Heigenhauser, Jones, & Spriet, 2015), and mental fatigue (Salam, Marcora, & Hopker, 2018). Among these, pedalling cadence and technique may be influenced by road gradient and characteristics directly affecting power output responses (Ansley & Cangley, 2009).

Cycling uphill elicits changes in important biomechanical and physiological parameters. Longer periods of neuromuscular activity and higher magnitudes of activation have been observed in the lower extremity during uphill cycling (Arkesteijn, Jobson, Hopker, & Passfield, 2013; Sarabon, Fonda, & Markovic, 2012). Decreases in efficiency and increased pedal force effectiveness have also been observed (Arkesteijn et al., 2013). Riding adopting a standing position, common in uphill cycling, results in the higher intensity and duration of neuromuscular activation for most muscles of the lower extremity (Duc et al., 2008), higher heart rate (Millet, Tronche, Fuster, & Candau, 2002), but lower rate of perceived effort (Tanaka, Bassett, Best, & Baker, 1996). Padilla, Mujika, Santisteban, Impellizzeri, and Goiriena (2008) observed that competitive stages with higher road gradients are related to higher physiological demands, as quantified by heart rate parameters and training impulse.

Another matter of concern for training monitoring and prescription using power output data are the different profiles adopted in cyclist specialization, such as those of uphill or flat specialists (Pinot & Grappe, 2011). In this sense, Sallet, Mathieu, Fenech, and Baverel (2006) observed a higher effect of cyclist's specialization on physiological parameters than a competitive level. Anthropometric characteristics due to their influence on aerodynamic resistance, are considered one of the main differences between flat and uphill specialists, the latter being in general lighter and smaller (Mujika & Padilla, 2001; Padilla, Mujika, Cuesta, & Goiriena, 1999; Peinado et al., 2011). For this reason, although flat specialists could present higher maximal cardiovascular performance as quantified by VO_{2max}, uphill specialists present higher values when these variables are normalized to the individual body mass (Mujika & Padilla, 2001; Peinado et al., 2011; Sallet et al., 2006). Uphill cyclists present differences in neuromuscular activation, such as a shorter range of vastus medialis and vastus lateralis activity, a longer period of biceps femoris activity, lower neuromuscular activation of tibialis anterior and higher neuromuscular activation of gluteus maximus (Sarabon et al., 2012). In addition, uphill specialists are attributed to the capacity to recruit additional type II fibres and to increase their firing rate (Lucía, Joyos, & Chicharro, 2000). These changes may result in a higher capacity of relative power output for climbers than flat specialists at high workload intensities (Pinot & Grappe, 2011), without differences in blood lactate responses (Padilla et al., 1999). In real conditions of outdoor cycling, competitive cyclists deal with various road gradients both during training and races, which can consequently influence their performance and their training responses regarding their specialty. Nevertheless, there is a lack of information regarding the possible influence of cycling specialization on the relation between power output and physiological response in the literature.

The aim of this study was to determine the effects of cyclist specialization on the rate of perceived exertion and physiological responses (heart rate and lactate) to uphill and flat cycling trials performed at the same power output. It was hypothesized that on two different road gradients matched by the same external load, uphill specialists would present lower effort perception and physiological response during uphill cycling than flat cyclists.

Materials and methods

Participants

Nineteen males cyclists classified as competitive road cyclists (Priego Quesada, Kerr, Bertucci, & Carpes, 2018) and club cyclists (Ansley & Cangley, 2009) participated in the study. Their mean ± SD age, body mass, height, cycling experience, and functional threshold power were 26 ± 8 years old, 65.8 ± 8.5 kg, 1.77 ± 0.06 m, 9 ± 7 years, and 4.8 ± 0.6 W^*kg^{-1}. As inclusion criteria, the cyclists had to be free of any chronic disease, not report any pain, be enrolled in systematic cycling training, and achieve an average power output between 4 and 6 W^*kg^{-1} in a time trial maximal effort test of 20 min in the field. Minimum experience of 1 year in the use of a mobile power metre for training and competition was also a criterion for inclusion. Participants gave their written informed consent before participation, and the local institution ethics committee approved the study. All procedures were in agreement with the Declaration of Helsinki.

Experimental design

The cyclists included in the study performed three tests within a period of 7 days. First, they performed a 20 min trial to determine the power output values targeted for the rest of the protocol. In the following 3–7 days they performed the two cycling trials where data were collected: flat trial and uphill trial. Flat and uphill trials were performed on the same day, being randomized and with a recovery period of one hour in between.

Procedures

Classification of participants. In this study, participants were classified in two different ways. Firstly, we conducted a short interview asking the cyclists about their role in the team and their perception of performance on flat and sloping terrains. Based on this information, they were classified as flat, all-rounder, or uphill specialists. Secondly, after the experimental phase, they were classified by the cluster analysis described below in the statistical analysis section.

Functional threshold power. On the first day of testing after a standardized warm-up including 10 min of cycling at preferred pedalling cadence and power output between 100 and 150 Watts, participants performed a 20-min maximal effort field time trial to determine their functional threshold power (FTP) (Allen & Coggan, 2010). The athletes were instructed to perform the trial at their highest sustainable power output throughout 20 min. FTP was recorded as 95% of the mean power output over the duration of the test (Allen & Coggan, 2010).

Flat and uphill trials. On the second day of testing after a standardized warm-up, consisting of 10 min of cycling at preferred pedalling cadence and power output between 100 and 150 Watts, participants completed two randomized trials of 10 min at 0% road gradient in a velodrome, and 10 min at 6% road gradient (field uphill, an average gradient of 6%, a minimum gradient of 5% and a maximum gradient of 7%), at an individual intensity of 10% ± 3% below FTP. Cyclists were requested to keep pedalling cadence between 75 and 80 rpm in both the trials. This cadence was selected for both trials since it is at an intermediate point between the cadence that is usually carried during flat and uphill cycling (Lucía, Hoyos, & Chicharro, 2001) and it allow to performed the relative intensity target without a decrease in power output and without need to change the gear ratio during pedalling. They were also instructed to maintain the same position and remain seated during both tests, which was verified by a video recording of the entire trial. In the 48 h previous to the tests the athletes were requested to avoid strenuous training sessions and keep to their regular diet. All trials were performed in similar environmental temperature (flat vs. uphill trial: 17.3 ± 4.7 vs. 17.1 ± 4.6°C; $p = 0.71$ and ES = 0.1) and at the same time of day. Average heart rate, speed, and cadence were recorded during the trials using a Garmin 310 XT (Garmin International, Inc., Kansas, USA). Power output was recorded using the same mobile power metre for all participants (PowerTap G3, Saris Cycling Group, Inc., Fitchburg, USA, accuracy of 1.5%), continuously displaying the absolute and normalized power output data (Bouillod, Pinot, Soto-Romero, Bertucci, & Grappe, 2017). Lactate and rate of perceived exertion (RPE) were assessed at the end of each trial. Blood lactate was measured using the Lactate Scout + system (SensLab CmbH, Leipzig, Germany and EKF Diagnostics GmbH, Barleben, Germany) (Tanner, Fuller, & Ross, 2010) from 5 µl blood samples collected from the ear lobe immediately after the distance was covered with the participants still on their bikes. RPE was measured using the CR6-20 scale (Borg, 1982). All participants were familiar to the Borg method. RPE was collected after the blood sample. Participants were presented with a printed scale and indicated the number corresponding to the effort perceived in that trial.

Statistical analysis

An a priori analysis of the sample size was performed with data from the first 8 participants assessed. The sample size was estimated using G*Power 3 software (University of Düsseldorf, Düsseldorf, Germany) and required the 18 participants to achieve a statistical power of 85%, α error of 5%, and large effect size (1.4) for comparing cycling specializations (uphill and flat) in the uphill trials. Having gathered all the data, statistical analyses were performed using SPSS software (v.21.0; IBM Armonk; USA). Results are reported as mean ± SD with 95% confidence intervals of the differences between conditions (CI95%). Data normality was confirmed using the Kolmogorov–Smirnov test with Lilliefors correction ($p > 0.05$). Characteristics (age, body mass, height, cycling experience, and functional threshold power) were compared between groups by independent t-tests. Differences between trials were determined using the paired-sample Student t-test. *K*-means cluster analysis was undertaken to group participants according to their internal load responses (the difference between both trials in lactate, heart rate, and effort perception). The cluster obtained using the responses of the three variables presented significant differences in 1/12 of the pair comparisons, 7/12 using only the lactate response, 2/12 using only heart rate response, and 5/12 using only effort perception response. Therefore, the lactate response was the variable selected to differentiate the groups by the *K*-means analysis given that it showed a higher number of differences between tests with the clusters obtained. Repeated measures ANOVA with one within-subject factor (trial) and one between-subject factor (cluster), with Bonferroni post-hoc, were performed for each parameter chosen to evaluate the differences between clusters and the differences between both trials in each cluster. The significance level was set at $p < 0.05$. Cohen's effect sizes (ES) were computed for the significant pair differences and classified as small (ES 0.2–0.5), moderate (ES > 0.5–0.8), or large (ES > 0.8) (Cohen, 1988).

Results

Without considering the cycling specialization, power output (flat vs. uphill: 284 ± 39 vs. 285 ± 40 W) and cadence (flat vs. uphill: 78 ± 4 vs. 77 ± 3 rpm) did not differ between flat and uphill trials ($p > 0.05$). Average speed was higher in the flat than in the uphill condition (38 ± 2 vs. 19 ± 2 km/h; IC95% of the difference [18, 19 km/h]; $p < 0.001$ and ES = 9.5). The average heart rate was higher in the uphill condition but with non-considerable effect size (167 ± 16 vs. 165 ± 15 bpm; IC95% of the difference [0.2, 3.7 bpm]; $p = 0.03$ and ES = 0.1). Blood lactate (flat vs. uphill: 3.4 ± 1.1 vs. 3.6 ± 1.6 mmol/l; $p = 0.43$) and RPE (flat vs. uphill: 14 ± 1 vs. 14 ± 1 points; $p = 1.00$) did not differ between the flat and uphill trials.

Table 1. Classification of the cyclists according to the individual perception of speciality, and by the *K*-means cluster analysis according to their internal load response including lactate response (1 for flat, 2 for uphill specialist).

Participant	Perception of speciality	*K*-means cluster
1	Flat	1
2	Flat	1
3	Flat	1
4	All-rounder	1
5	All-rounder	1
6	All-rounder	1
7	All-rounder	1
8	All-rounder	1
9	All-rounder	2
10	All-rounder	2
11	All-rounder	2
12	All-rounder	2
13	Uphill	1
14	Uphill	2
15	Uphill	2
16	Uphill	2
17	Uphill	2
18	Uphill	2
19	Uphill	2

Cycling specialization

Based on the short interviews with the participants, there were 3 flat, 9 all-rounder, and 7 uphill specialists among the 19 participants (Table 1). *K*-means cluster analysis showed that considering the difference between both trials, blood lactate concentration identified two different groups of cyclists, 9 being flat and 10 being uphill specialists. Flat and uphill specialists were in different clusters in most of the cases (except participant 13), and all-rounders were distributed in both groups (Table 1). In the following analysis, clusters 1 and 2 were considered as flat and uphill specialists, respectively. Clusters did not differ regarding demographic characteristics (Table 2).

Effect of cycling specialization on the RPE and physiological responses

Uphill specialists reported lower RPE (IC95% [0.4, 2.6 points]; $p = 0.01$ and ES = 1.3) and lower blood lactate concentration (IC95% [0.6, 3.2 mmol/l]; $p < 0.01$ and ES = 1.4) in the uphill trial compared to the flat specialists (Figure 1).

Flat specialists showed lower RPE (IC95% [0.4, 1.4 points]; $p < 0.01$ and ES = 0.7), heart rate (IC95% [2.0, 6.2 bpm]; $p < 0.001$ and ES = 0.2), and blood lactate concentration (IC95% [0.7, 1.4 mmol/l]; $p < 0.001$ and ES = 0.7) in the flat trial compared to the uphill trial (Figure 1).

Table 2. Characteristics of each cluster (mean ± standard deviation).

	Cluster		Flat versus Uphill specialist		
	Flat (1)	Climber (2)	p	ES	Diff. (CI95%)
Age (years)	23 ± 6	28 ± 9	0.11	0.74	−13, 2
Body mass (kg)	67.5 ± 10.4	64.3 ± 6.6	0.43	0.37	−5.14, 11.54
Height (m)	1.77 ± 0.06	1.77 ± 0.05	0.90	0.05	−0.06, 11.54
Cycling experience (years)	8 ± 6	10 ± 8	0.91	0.29	−8, 5
functional threshold power (W/kg)	4.87 ± 0.55	4.80 ± 0.58	0.79	0.13	−0.48, 0.62

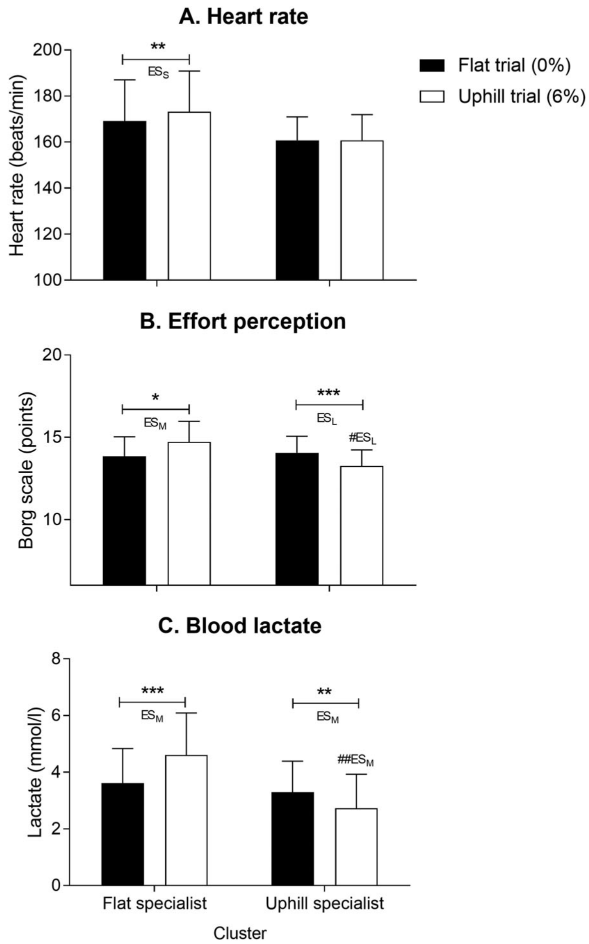

Figure 1. Results from internal load (A. heart rate; B. rate of perceived effort; C. blood lactate) responses in the flat and uphill clusters. Differences are identified by symbols (* $p < 0.05$ uphill vs. flat trial; ** $p < 0.01$ uphill vs. flat trial; # $p < 0.05$ flat vs. uphill cluster; ## $p < 0.05$ flat vs. uphill cluster) and effect size (large effect size ES_L; moderate effect size ES_M; small effect size ES_S).

Conversely, uphill specialists presented higher RPE (IC95% [0.3, 1.3 points]; $p < 0.01$ and ES = 0.8) and lactate responses (IC95% [0.2, 0.9 mmol/l]; $p < 0.01$ and ES = 0.5) in the flat trial compared to the uphill trial.

Discussion

In this study we set out to determine the effects of cyclists specialization on effort perception and physiological responses to cycling at two different road gradients matched by the same external load. Our main finding is that cyclists of different specializations, exercising at the same external load, report different rates of perceived exertion and physiological response.

We ensured that flat and uphill trials performed were correctly matched for the power output, cadence, and posture (both seated). The only difference between flat and uphill trials was the speed, lower in the uphill trial. The lower speed while riding uphill is explained by the greater opposing force resulting from gravity (Fonda & Šarabon, 2012). Heart rate was higher in the uphill than in the flat trial, but the no effect size observed suggests that the difference may not affected the performance. Therefore, we consider that physiological response did not differ between flat and uphill trials regardless of the cyclist specialization, which is in agreement with a previous study comparing flat and uphill performance (Padilla et al., 1999). However, the main novelty of our study is that it shows that when cycling specialization is considered, there are important changes in the results. When cycling specialization is considered, the effort perception and physiological responses are significantly affected by both cyclist specialization and road gradient. We suggest that studies on uphill cycling performance should consider the cyclist specialization during the recruitment of the participants, as well as when interpreting the results. From an applied point of view, the use of power output information to monitor and control training and competitive performance also needs to consider this specialization effect.

Specialization had an important effect on effort perception and physiological responses on comparing flat and uphill trials performed at the same relative power output. Uphill specialists presented lower RPE and blood lactate during uphill than in the flat trial, and flat specialists presented inverse results. Previous investigations have shown how intensity, magnitude, and timing of the neuromuscular activation of lower limbs differ between flat and uphill cycling (Arkesteijn et al., 2013; Duc et al., 2008; Sarabon et al., 2012). This suggests an effect of cycling specialization on neuromuscular activation parameters, helping to explain our results. Anthropometric characteristics or power output production capacity could be another important factor to explain the physiological response differences between groups (Ansley & Cangley, 2009; Foley, Bird, & White, 1989; Lee, Martin, Anson, Grundy, & Hahn, 2002; Mujika & Padilla, 2001; Peinado et al., 2011), but the two clusters identified did not present differences in body mass, height, and functional threshold power. Furthermore, all these trials took power output normalized to the body mass into consideration. Further research should try to analyze the differences in neuromuscular activity characteristics between uphill and flat specialists, and how these parameters could explain differences in performance during uphill or level ground efforts.

The specialization of the cyclists in this study was determined from *K*-means cluster analysis considering lactate responses. This grouping was very similar to the opinion that cyclists had about themselves as being an uphill or a flat specialist. This is in agreement with a previous study that obtained, using a two discriminant test, that the first criteria to classify cyclists is the classification performed by their trainers (Peinado et al., 2011). In this case, it seems that the trainers' or cyclists' perception can be enough to predict whether they will be more efficient in terms of effort perception and physiological response depending on the slope of the terrain. Nevertheless, many cyclists perceived themselves as all-rounders. Anthropometric characteristics are another important criteria for cycling specialization classification (Peinado et al., 2011), but cycling specialization should not considerer anthropometric data alone, as cyclists with similar morphotype can be classified in different clusters, and in mountain stages, lighter cyclists have shared top positions with heavier cyclists (Padilla et al., 1999). Therefore, all these may emphasize the need to conduct uphill and flat trials matched by the same power output, to differentiate the performance of these cyclists in flat and uphill trials. Finally, exercise duration is an important performance indicator in cycling. We tested flat and uphill performance at similar times (10 min). We considered that 10 min were enough to promote physiological adaptations without resulting in fatigue (based in Borg' scale results), which would not be possible with shorter trials (Bouillod & Grappe, 2018).

The preferred cadence could vary according to the specialization of the cyclists. The preferred cadence is usually higher during flat pedalling than during uphill (Ansley & Cangley, 2009). Although this may have affected our results, we believe that this is preferable to the use of different cadences between tests, as it is a factor that has an important effect on neuromuscular, cardiovascular and perceptual efficiency and could invalidate our methodological approach (Ansley & Cangley, 2009; Faria, Parker, & Faria, 2005).

The results of the present study have an important practical application, showing the need to take this information into account in combination with specialization to better adjust training loads. In addition, coaches could consider the cyclist specialization before prediction performance. In this sense, field tests are generally performed only on one road gradient, although athlete specialization could impact on the results. Future studies could explore the differences in effort perception and physiological response by considering a sample of professional cyclists. As a field study, our experiment has some limitations. We considered a 6% road gradient, and therefore we cannot generalize our results to steeper gradients in which uphill specialization may result in more particular responses. We were not able to measure pedal forces and asymmetries, which could help to understand if the physical responses in training load may also be affected by pedalling technique. Despite the limitation of calculating the functional threshold power as 95% mean power output of the 20-min test (Borszcz, Tramontin, Bossi, Carminatti, & Costa, 2018), it is important to bear in mind that this test was used to determine the relative intensity of the flat and uphill trials. Other tests could also be used with this purpose in the context of our study.

In conclusion, cyclists with different specialization (flat or uphill specialists), exercising at the same external load, report lower effort perception and physiological response when riding on their typical specialization road gradient. We suggest that the control of training load, performance prediction and scientific research, based on power output, may need to consider the road gradient and the cyclist specialization due to its effect on effort perception and physiological response.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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