The physiological parameters, training characteristics and race performance in highly trained cyclists. A cross-sectional study

Parámetros fisiológicos, características del entrenamiento y el rendimiento en competición en ciclistas entrenados. Un estudio transversal

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Abstract

Introduction: Physiological parameters such as maximum oxygen uptake (VO_{2max}), Absolute and Relative Peak Power Output (PPO, PPO·kg^{-1}) and Maximal Fat Oxidation (MFO) are critical parameters in cycling performance and race success.
Objective: This study was designed to explore these physiological parameters and training characteristics of Under 23 (U23), Elite and Master 30 (M30) cyclists and its association with races' performance.
Method: A cross-sectional study was conducted with thirty-four highly trained road cyclists (28.3 ± 7.4 years, 177.4 ± 6.0 cm, 68.4 ± 7.3 kg) who performed a VO_{2max} test at the beginning of the pre-season period. Linear regressions were performed to examine the association between physiological parameters and weekly training hours. Analysis of Covariance (ANCOVA) was used to compare each physiological parameter across competitive categories while adjusting for weekly training hours as a covariate. Statistical significance was set at $p < 0.05$.
Results: A positive association was observed between training hours and VO_{2max}, PPO and PPO·kg^{-1} (all $p < 0.05$). No association was found between training hours and MFO. Significant differences were found between categories in terms of VO_{2max}, PPO and PPO·kg^{-1} (all $p < 0.05$) where Elite and U23 cyclists overperformed M30 cyclists, while no significant differences were found in MFO. No significant associations were observed between race performance and the physiological parameters mentioned.
Conclusion: Training volume in highly trained cyclists appears to be a key determinant of aerobic performance in VO_{2max}, PPO and PPO·kg^{-1}. Elite and U23 cyclists showed higher VO_{2max} and PPO·kg^{-1} values than M30 cyclists, likely due to their training status and races demands.

Keywords

Amateur cyclists; maximal fat oxidation; peak power output; road cycling; VO_{2max}.

Resumen

Introducción: Parámetros fisiológicos como el consumo máximo de oxígeno (VO_{2max}), la potencia pico absoluta y relativa (PPO, PPO·kg^{-1}) y la oxidación máxima de grasas (MFO) son determinantes clave del rendimiento en ciclismo y del éxito en competición.
Objetivo: Este estudio se diseñó para explorar estos parámetros fisiológicos y las características del entrenamiento en ciclistas de las categorías Sub-23 (U23), Élite y Máster 30 (M30), así como su asociación con el rendimiento en competición.
Método: Un estudio transversal fue realizado con treinta y cuatro ciclistas de carretera entrenados (28,3 ± 7,4 años; 177,4 ± 6,0 cm; 68,4 ± 7,3 kg) que realizaron una prueba de VO_{2max} en el inicio de la pretemporada. Se realizaron análisis de regresión lineal para examinar la asociación entre los parámetros fisiológicos y las horas de entrenamiento semanales. Se utilizó Análisis de Covarianza (ANCOVA) para comparar los parámetros fisiológicos entre las diferentes categorías competitivas, ajustando por las horas de entrenamiento semanales como covariable. La significación estadística se estableció en $p < 0.05$.
Resultados: Se observó una asociación positiva entre las horas de entrenamiento y el VO_{2max}, la PPO y la PPO·kg^{-1} (todos $p < 0.05$). No se encontró asociación entre las horas de entrenamiento y la MFO. Se observaron diferencias significativas entre categorías en VO_{2max}, PPO y PPO·kg^{-1} (todos $p < 0.05$), donde los ciclistas Élite y U23 mostraron valores superiores a los de los ciclistas M30, mientras que no se encontraron diferencias significativas en la MFO. No se observaron asociaciones significativas entre el rendimiento en competición y los parámetros fisiológicos analizados.
Conclusiones: El volumen de entrenamiento en ciclistas entrenados parece ser un factor clave del rendimiento aeróbico, reflejado en el VO_{2max} la PPO y la PPO·kg^{-1}. Los ciclistas Élite y U23 mostraron valores superiores VO_{2max} y PPO·kg^{-1} que los ciclistas M30, debido a su estado de entrenamiento y a las demandas competitivas.

Palabras clave

Ciclistas amateurs; ciclismo en ruta; oxidación máxima de grasas; potencia pico; VO_{2max}.

Introduction

Road cycling has been classified as a physiologically demanding endurance sport, mainly because of the exercise time which is required in some of the races combining in-line races characterized by flat to mountainous terrain and individual and team time trials (Pérez-Landaluce et al., 2002). On the one side, in professional cycling, there are distances from 5km to almost 300km and competitions range from one day to twenty-one days (Fernández-Garcia et al., 2000). Regardless of the long distances, exercise intensity is exceptionally high since it can get to high percentages like 90% of VO_{2max} (i.e. long climbs or time trials) and even superior to Anaerobic Threshold (VT2) [i.e. sprints or short hills] (Lucía et al., 2001). Accordingly, cyclists must train to cover the distance and to perform as much as possible. A 4-year retrospective analysis (Van Erp et al., 2022) demonstrated how much volume professional (PRO) cyclists trained throughout a season. Some studies have focused on how PRO cyclists train for twenty-one-day races (i.e. grand tour) (Gallo et al., 2023; Gallo et al., 2022) whilst others considered the effects of training hours on physiological parameters such as VO_{2max} (Cove et al., 2025).

On the other side, in amateur cycling at national level, which is considered the step before jumping to professional level, each cycling federation stipulates their own norms based on the Union Cycliste International (UCI) statements. The "Amateur" concept remains unclear as it includes athletes from a wide range of levels, from those categories such as Elite and U23 who want to step up to PRO cycling to others as Master's categories that compete on its age category (Hovorka et al., 2023; Leo et al., 2022). As it is stablished on the Real Federación Española de Ciclismo (RFEC) normative, Elite and U23's competitions in Spain are up to 240 km and range from one to six days of competition and M30's category are up to 120 km (RFEC, 2025). Recently, a study from Gallo et al. (2022) compared the racing characteristics between junior (JUN), Under 23 (U23) and PRO and exposed that PRO had significantly more races, longer duration and more meters of elevation per race. Additionally, some investigations have reported physiological data in master cyclists, including M30 cyclists; however, these data were analyzed in isolation and without direct comparison to Elite, U23 or PRO cyclists (Nikolaïdis & Papadopoulos, 2011; Peiffer et al., 2008).

Several physiological parameters have been examined and are determined as critical for road cycling (Sallet et al., 2006). In trained cyclists, the VO_{2max} measured via respiratory gas exchange is a gold standard for endurance sports (Denham et al., 2020; Midgley et al., 2006) and it is strongly related with PPO (Hawley & Noakes, 1992). Recently, a study from Alejo et al. (2022) demonstrated that PRO cyclists had statistically significant differences in relative and absolute PPO and power output at Ventilatory Threshold but did not show statistically significant differences in terms of VO_{2max} compared with U23. Power at Aerobic Threshold (VT1) and VT2 are also critical parameters in cycling performance and some studies attempted to identify normative data considering power at VT1 and VT2 in males (Leo et al., 2022) and also the percentage of VO_{2max} utilization at each threshold in females (Cano-Giraldo et al., 2025). Lucía et al. (1998) found that power at VT1 and VT2 is higher at PRO level than amateur. Moreover, some studies have provided normative data in their results from JUN (Menaspà et al., 2012) and PRO cyclists (Mujika & Padilla, 2001; Valenzuela et al., 2022; Van Erp et al., 2022), whilst others compared JUN and U23 that want to step up to PRO level (Hovorka et al., 2023; Leo et al., 2022). While endurance markers such as VO_{2max}, PPO and PO at Ventilatory Thresholds (VT) are commonly investigated, parameters related to fat oxidation (FAT_{ox}), including Maximal Fat Oxifation [MFO] (measured in $g \cdot min^{-1}$), have been mainly investigated in PRO or recreational populations (Maunder et al., 2018; San-Millán & Brooks, 2018). The Integration of MFO, whose maximal capacity occurs between 45 to 65% of VO_{2max} (Jeukendrup & Achten, 2001; Purdom et al., 2018), with power-based metrics is rarely reported across competitive amateur categories. Nonetheless, San-Millán & Brooks (2018) studied FAT_{ox} in PRO and cyclists and sedentary people and stated that PRO achieve MFO at higher exercise intensities compared to sedentary.

With no use of laboratory equipment, other parameters have risen from field tests such as Functional Threshold Power (FTP) which is calculated from a 20-min or 8-min test and multiplicated per 0.95 or 0.90, respectively to achieve the power that a cyclist can get for one hour (Allen & Coggan, 2010; Denham et al., 2020) and also time to exhaustion (TTE), the time that FTP is sustained, which should be investigated individually (Sitko et al., 2022).

This study was designed to explore the physiological and training characteristics of U23, Elite and M30 cyclists. First, it aimed to analyse the association between volume in hours per week ($h \cdot wk^{-1}$) and physiological parameters focusing on VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$), PPO (w), $PPO \cdot kg^{-1}$ ($w \cdot kg^{-1}$), MFO ($g \cdot min^{-1}$) and second, to compare these physiological parameters with their category (U23, Elite, M30) and their performance in races. It is hypothesized that U23 and Elite cyclists will have better physiological parameters than M30, and the cyclists with higher physiological parameters will perform better in races.

Method

This cross-sectional observational study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (Von Elm et al., 2014). Physiological data from road cyclists was collected under supervised laboratory conditions, whereas training and performance in official road races were obtained retrospectively from federation records. The study design and procedures were conducted following the Declaration of Helsinki and its later amendments and were approved by the Research Ethics Committee of the Universitat de Vic – Universitat Central de Catalunya (222/2022).

Participants

Participants were recruited based on the inclusion criteria, ensuring that all met the classification of "Highly trained" (McKay et al., 2022). The inclusion criteria were 1) to have a current Federation License, 2) to have ridden a minimum of 1 road race throughout the season and 3) At least 2 years of structured training. The exclusion criteria were 1) to be injured during the month before the test or to report chronical injuries that affects negatively the performance, 2) to report health issues one week before the test and 3) to take performance enhancement medication banned from the World Agency of Doping Association (WADA) or the UCI.

The investigators of the study recruited all participants from their social networks advertising the existence of the investigation showing the inclusion and exclusion criteria. Thirty-four highly trained cyclists (28.1 ± 7.4 years, 177.4 ± 6.0 cm, 68.3 ± 7.1 kg) were eligible for the study. This sample forms part of a longitudinal study for which an a priori power analysis confirmed adequate statistical power. Given the reduced sample size and unequal group distribution in the current cross-sectional analyses, a sensitivity analysis was conducted using G*Power (v3.1) based on a one-way fixed-effects ANOVA design (three groups, total $N = 34$, $\alpha = 0.05$, power = 0.80), providing a conservative estimate of statistical sensitivity given the unequal group sizes. The analysis indicated that the present sample was sufficiently powered to detect medium-to-large effects ($f = 0.45$-0.50; equivalent to $\eta^2p = 0.17$-0.20), whereas smaller effects may have remained undetected. After comprehensive verbal and written explanations of the study and all its aims, all subjects gave their written informed consent for participation. Every participant could withdraw from the study at any moment.

Procedure

Physiological assessments were conducted at the physiology laboratory of the Universitat de Vic – Universitat Central de Catalunya. Data collection was performed in November 2022 and November 2023, at the start of the cyclists' preseason period, corresponding to the early preseason period (after 2–4 weeks of resumed training, i.e., introductory mesocycle). Tests conducted in November 2022 were linked with training and performance data from the 2022 season, whereas tests conducted in November 2023 were linked with data from the 2023 season. Training volume and racing performance was analyzed for the road cycling season. The Spanish amateur Road cycling season typically runs from February to September; therefore, training data were analyzed from 1 November to 30 September of each season. October was excluded as an off-season period.

All participants came one time to the physiology laboratory to perform a VO_{2max} test on an electronically braked cycle ergometer (Excalibur Sport; Lode, Groningen, The Netherlands). Participants wore a face mask covering their mouth and nose (Hans Rudolph, Kansas City, MO) and recorded and monitored all measures breath by breath (Quark; Cosmed, Rome, Italy). Each participant set the saddle and handlebar heights to match their usual position on their own bikes. The cycle ergometer was equipped with mountain bike *Shimano®* racing pedals and toe clips, allowing everyone to wear their own shoes.

The test protocol was based on Marquet et al. (2016) and consisted of a warm up of 6 minutes at 100W and then the power output was increased by 25 W each 2 minutes until volitional exhaustion with self-selected cadence. During the test, oxygen uptake (VO_2), carbon dioxide uptake (VCO_2), minute ventilation (VE), Respiratory Exchange Ratio (RER) and Heart Rate (HR) were continuously recorded. Gas and flow analyzers were calibrated before each test using ambient air, known concentration gas, and a 3-L syringe. VO_2max was determined based on the highest 30-s moving average value. PPO (W) was calculated as the last completed workload + 25 (t/120), where *t* is the number of seconds in the last workload.

Prior to the VO_{2max} test, all subjects followed a standardized carbohydrate intake to ensure the same glycogen availability to perform the test. The nutritional protocol consisted of a moderate to high dose of carbohydrate meal and following the patterns of Burke et al. (2011). Thus, all participants consumed from 6 to 7 g/kg of body weight (BW) of a combination from low to middle glycaemic carbohydrates distributed in 5 meals during the day before the test. The meal before the test was also standardized as they consumed a low to middle glycaemic carbohydrate meal (from 1.5 to 2.0 g/kg BW).

All tests were always performed by the same investigator under standardized conditions. All participants received a document to reduce the non-controlled changes on performance and had to follow the instructions of the investigators. Everyone had the similar verbal encouragement during testing. All participants had to follow the same nutritional protocol and cannot do the following:

- Smoke or drink alcohol.
- To get exposed to the sun or UV.
- Perform an intensive of high-fatigue session 24h before the test.
- Eat from two hours before the test.
- Drink coffee or other stimulating substances two hours before the test.
- Consume medicines or others.

Data from training sessions was analyzed with WKO5 Build 583 Software (Boulder, Colorado, USA) and all trainings independently of what bike discipline (i.e. road bike, mountain bike or cyclocross bike) and gym sessions were considered. The races analyzed were those who have been registered on www.firstcycling.com and www.ciclisme.cat. Both websites are databases where the results of all participants may be matched.

Potential selection of Bias was minimised by recruiting cyclists from clubs that are used to race in official competitions, although most of them had proximity with the investigators of this study and may not be fully representative of the whole region of Catalunya. Retrospective data on training hours was collected using a cycling performance software analyzer (WKO5) in order to avoid recall bias from the participants.

Variables

The primary outcome variable analyzed after physiological tests was the VO_{2max} measured in $ml \cdot kg^{-1} \cdot min^{-1}$ and was taken by using the gas analyser during the incremental cycling test. Secondary variables were measured such as PPO (w) and its ergonomic index relative to body weight ($W \cdot kg^{-1}$) and MFO ($g \cdot min^{-1}$). MFO was defined as the highest Fat_{ox} rates in the second minute of the stage and were calculated using Frayn's stoichometric equations (Frayn, 1983), based on VO_2 and VCO_2 ($L \cdot min^{-1}$):

$$Fat\ oxidation = 1.67 \times VO2 - 1.67 \times VCO2$$

Cyclists' characteristics variables were age (years), weight (kg), height (cm) and category (U23 – cyclists between 18 and 22 years; Elite – cyclists older than 22 years with elite license; M30 cyclists between 30 to 39 years with Master 30 license). The weekly volume ($h \cdot wk^{-1}$) for each individual through their annual training period was analyzed as well as the number of races done throughout the year, considering the best results (top10) on the general classification of road races. The use of top-10 finishes as a performance indicator was chosen based on the study of Van Erp & Sanders (2021) that compared a "good" result (e.g. top-10) versus no result (e.g. no top-10). In order to differentiate the level of the races that participants rode, road races are divided in two groups: national races (1) and regional races (2). Cyclocross and mountain bike races were excluded. The performance in races was categorized in three groups: Group 1: at least one top10 in National Races (Spanish Ranking); Group 2: at least one top10 in Regional Races (Catalan Ranking); Group 3: no top10 in any race.

Data analysis

Descriptive statistics were calculated to summarize the main characteristics of the sample and are presented as mean ± standard deviation (SD). Simple linear regression analyses were used to examine the association between cyclists' physiological characteristics (VO_{2max}, PPO, $PPO·kg^{-1}$, and MFO) and their weekly training volume ($h·wk^{-1}$). Results were summarized using standardized coefficients (β), t-statistics, and 95% confidence intervals (CIs). Analysis of covariance (ANCOVA) was performed to compare each physiological parameter (VO_{2max}, PPO, $PPO·kg^{-1}$, and MFO) across competitive categories (Junior, U23, and M30) while adjusting for weekly training hours as a covariate. When significant main effects were identified, Tukey-adjusted post-hoc comparisons were conducted, which control the family-wise error rate across multiple pairwise comparisons. Model diagnostics were performed for both linear regressions and ANCOVA models. Residual normality was assessed using visual inspection of Q–Q plots and Shapiro–Wilk tests. Homoscedasticity was evaluated through residuals versus fitted values plots, and linearity was verified by inspection of partial regression plots. No major violations of assumptions were observed. Effect sizes for ANCOVA were reported using partial eta-squared (η^2p) and Cohen's d for post-hocs comparisons, with corresponding 95% confidence intervals (CIs). The effect size for η^2p was interpreted as: 0.01 to 0.06 = small; 0.06 to 0.14 = medium; and > 0.14 = large; and for Cohen's d was interpreted as : <0.20 = trivial; 0.20-0.59 = small; 0.60-1.19 = moderate; 1.20-1.99 = large; and >2.00 = very large (Hopkins et al., 2009). The statistical significance was set at $p < 0.05$. All statistical analyses were performed using JASP software (version 0.19.3; University of Amsterdam, The Netherlands).

Results

Thirty-four cyclists (9 U23, 19 Elite, 6 M30) were included in final analyses. Descriptive statistics are presented in table 1.

Table 1. Descriptives of variables of interest (VO_{2max}, PPO, PPO·kg-1, MFO and Training hours). Data is presented as mean ± SD

CATEGORY	VO_{2max} ($ml·kg^{-1}·min^{-1}$)	PPO (w)	$PPO·kg^{-1}$ ($w·kg^{-1}$)	MFO ($g·min^{-1}$)	TRAINING HOURS ($h·wk^{-1}$)
U23	65.1 ± 5.8	386 ± 28	6.0 ± 0.5	0.37 ± 0.11	12.8 ± 2.5
ELITE	65.2 ± 6.4	406 ± 32	5.9 ± 0.4	0.41 ± 0.19	13.5 ± 4.0
M30	56.7 ± 5.3	366 ± 46	5.0 ± 0.5	0.32 ± 0.14	11.3 ± 3.0

Simple linear regressions showed associations in some physiological parameters with weekly training volume, see *Figure 1*. Training hours were associated with VO_{2max} (β = 0.34, t = 2.04, p = 0.049) explaining a proportion of the variance (R^2 = 11.5%). Each additional hour per week was associated with an increase of 0.65 $ml·kg^{-1}·min^{-1}$ in VO_{2max} (95% CI [0.002, 1.303]). Training hours were associated with PPO (β = 0.36, t = 2.17, p = 0.038), explaining a proportion of the variance (R^2 = 12.8%). Each additional training hour per week was associated with an increase of 3.70 watts in PPO (95% CI [0.22, 7.17]). Training hours were associated with $PPO·kg^{-1}$ (β = 0.39, t = 2.36, p = 0.024 explaining a proportion of the variance (R^2 = 14.9%). Each additional training hour per week was associated with a rise of 0.06 $w·kg^{-1}$ (95% CI [0.008, 0.113]). Training hours were not related to MFO (β = 0.09, t = 0.49, p = 0.626).

Differences between categories and physiological parameters from the ANCOVA models can be found in *Figure* 2. For VO_{2max}, there were differences between categories (F(2,30) = 3.75, p = 0.035, η^2p = 0.20, *large*) but no significant differences in weekly training hours (F(1,30) = 2.46, p = 0.128, η^2p = 0.08, *medium*). Post-hoc comparisons showed Elite had greater VO_{2max} than M30 (mean difference = -7.41 $ml·kg^{-1}·min^{-1}$, d = -1.25, 95% CI [-2.54, 0.04], p = 0.038, *large*). Although the comparison between U23 and M30 did not reach statistical significance (p = 0.055, mean difference = 7.66 $ml·kg^{-1}·min^{-1}$, d = 1.29, 95% CI [-0.13, 2.70], *large*), the large effect size suggests a potentially meaningful difference that may not have reached significance due to limited power. No differences were present between U23 and Elite (p = 0.994, mean difference = 0.25 $ml·kg^{-1}·min^{-1}$, d = 0.04, 95% CI [-0.99, 1.07], *trivial*). For PPO, there were no statistically significant differences between categories (F(2,30) = 2.51, p = 0.098, η^2p = 0.14, *large*). However, the *large* effect size suggests a potentially meaningful difference that may have no reached statistical significance due to limited statistical power. For PPO·kg^{-1}, there were differences between categories (F(2,30) = 10.23, p = <.001, η^2p = 0.405, *large*). Post-hoc comparisons indicated significant differences between U23 and M30 (p = <.001, difference = 0.93 w·kg^{-1}, d = 2.28, 95% CI [0.73, 3.82], *very large*) and M30 and Elite (p = 0.001, difference = -0.79 w·kg^{-1}, d = -1.93, 95% CI [-3.30, -0.55], *large*) and no significant differences between categories U23 and Elite (p = 0.668, difference = 0.14 w·kg^{-1}, d = 0.35, 95% CI [-0.69, 1.39], *trivial*). For MFO, no differences were present between categories (F(2,30) = 0.51, p = 0.603, η^2p = 0.03, *small*), nor the weekly training hours (F(1,30) = 0.06, p = 0.817, η^2p = 0.002, *trivial*). No differences were found between VO_{2max} (F(2,30) = 1.87, p = 0.17, η^2p = 0.10, *medium*), PPO (F(2,30) = 1.63, p = 0.21, η^2p = 0.08, *medium*), PPO·kg^{-1} (F(2,30) = 2.62, p = 0.09, η^2p = 0.13, *medium*) and MFO (F(2,30) = 1.44, p = 0.25, η^2p = 0.09, *medium*) and racing performance.

Figure 1. Linear regressions of weekly training volume on VO_{2MAX}, PPO, PPO·kg^{-1} and MFO.

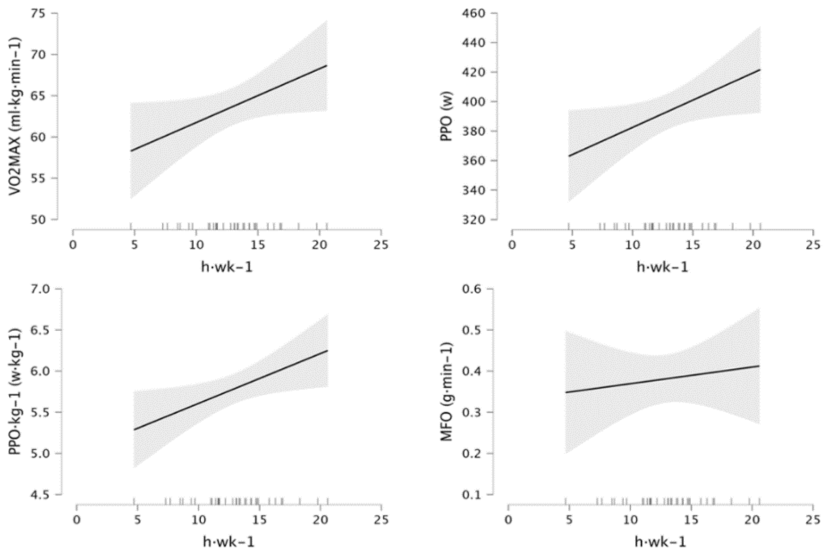
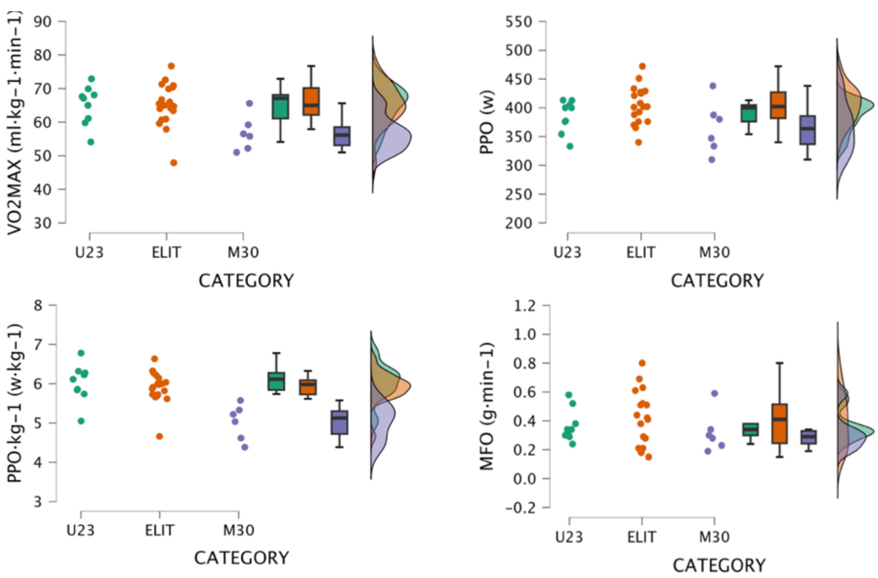


Figure 2. Comparative graphics for each physiological parameter comparing categories



Discussion

The present study aimed to explore the physiological parameters and training characteristics of U23, Elite and M30 cyclists with a particular focus on the relationship between weekly volume and key indicators of endurance performance with the cyclist's category and performance in races. The main findings revealed a positive association between training hours and VO_{2max}, PPO and PPO·kg^{-1}. However, there was no association between training hours and MFO. Significant differences were found between categories in terms of VO_{2max}, PPO and PPO·kg^{-1} where Elite and U23 cyclists overperformed M30 cyclists, while no significant differences were found in MFO. No significant associations were observed between race performance and the physiological parameters mentioned.

The results of the present study showed a positive association between training hours and VO_{2max}, PPO and PPO·kg^{-1} which suggests that greater training volume is associated with enhanced physiological parameters. Nonetheless, training hours explained a moderate proportion of the variance (11-15%) suggesting that other training factors such as training intensity distribution, genetics predisposition, years of experience and recovery strategies are also involved in the physiological parameters analyzed (Cove et al., 2025). Surprisingly, MFO was not significantly associated with weekly training hours and suggests that fat oxidation capacity may depend on training intensity (Jeukendrup & Achten, 2001), nutritional periodization (Marquet et al., 2016) or genes expression (Psilander et al., 2013). No differences in weekly hours were found between categories and all of them were lower than PRO cyclists (Gallo et al., 2023; Gallo et al., 2022). The number of races throughout a season, the length and meters of elevation are lower in U23 and Elite than PRO cycling (Fernández-Garcia et al., 2000; Gallo et al., 2022) but longer and harder than M30 races (RFEC, 2025); thus, the hours of preparation varies according to the races demand.

VO_{2max} values had significant differences between categories, with Elite and U23 cyclists showing greater values (*large effect*) than M30 cyclists (65.2 ml·kg^{-1}·min^{-1}, 65.1 ml·kg^{-1}·min^{-1} vs 56.7 ml·kg^{-1}·min^{-1}, respectively), although the difference between U23 and M30 did not reach statistical difference. The lack of difference between Elite and U23 cyclists suggest that U23 cyclist still have room for improvement until they achieve a certain training maturity. In addition, VO_{2max} values observed in the present study were relatively high, although not as high as those reported in some studies in Elite [78.8 ml·kg^{-1}·min^{-1}] and U23 [76.2 ml·kg^{-1}·min^{-1}] (Leo et al., 2022; Mujika & Padilla, 2001). While M30 cyclists also showed relatively high VO_{2max} values, those were more similar to those reported in a normative study (58.5 ml·kg^{-1}·min^{-1}) of (Nikolaïdis & Papadopoulos, 2011; Peiffer et al., 2008). To the authors' knowledge, two cyclists of the current study stepped up to PRO cycling in the following months after the study, although having lower VO_{2max} relative values (66.7 and 69.9 ml·kg^{-1}·min^{-1}) compared to the samples of (Leo et al., 2022). This lower VO_{2max} values may be partially explained by differences in testing protocols and the moment of the season as Leo et al. (2022) performed a ramp incremental exercise test in March (the start of the season) beginning at 150 W and was increased by 20 W·min^{-1}. These two cyclists showed similar relative PPO (6.1 and 6.8 w·kg^{-1}) compared to the samples of Leo et al. (2022) [6.8 w·kg^{-1}] and Mujika & Padilla (2001) [6.4 w·kg^{-1}]. This finding supports the idea that VO_{2max} should be considered along with other physiological parameters.

In the present study, absolute PPO was not different between groups whereas PPO·kg^{-1} did show differences (*large effects*) between categories, where both Elite and U23 (5.9 W·kg^{-1} vs 6.0 W·kg^{-1}, respectively) categories have higher relative power output than M30 (5.0 W·kg^{-1}). Body mass in younger cyclists on the present study was lower than the older and may explain the contrast between categories as PPO·kg^{-1} integrates both aerobic capacity and body composition. U23 and Elite are categories that want to raise to PRO; for this reason, physiological parameters tend to be better than M30, coinciding with studies with PRO cyclists on their samples (Hovorka et al., 2023; Leo et al., 2022). Furthermore, relative power output was significantly associated with VO_{2max} in contrast with the study of Hawley & Noakes (1992) that mentioned to absolute power output. No differences were observed in MFO between categories; it seems that fat oxidation capacity is preserved independently of the category as the sample is highly trained endurance cyclists (Mittendorfer & Klein, 2001; Sial et al., 1998). Nonetheless, other studies mentioned that MFO decreases with aging (Frandsen et al., 2021; Toth & Tchernof, 2000). Moreover, the MFO from the sample of this study may be considered in the 20th percentile of Maunder et al. (2018) normative data.

None of the physiological variables analyzed were significantly related to racing performance in contrast with some studies (Hovorka et al., 2023; Leo et al., 2022; Mirizio et al., 2021). Interestingly, a study from Impellizzeri et al. (2005) mentioned that aerobic fitness explained only a 40% of the variance, which means that factors such as tactical and strategical decisions, techniques, team roles, environmental conditions or mentality should be considered. Moreover, the variability of the races (i.e. stage races, one-day races, time-trial), the terrain (flat, mountain) and competition level (Fernández-Garcia et al., 2000; Lucía et al., 2001; Pérez-Landaluce et al., 2002) might have impaired potential associations between the physiological variables analyzed with race performance. Further investigation ought to be focused on how these variables play an important role for race success to complement laboratory assessments.

This study is not without limitations. The main limitation of this study was the small sample size (n = 34), which resulted in a heterogeneous group size across cycling categories. A larger sample size would improve group comparability and increase the precision of the findings. In any case, this sample represents only the baseline of the wider longitudinal cohort, the present cross-sectional results should therefore be interpreted with caution. Therefore, the absence of significant differences should be interpreted cautiously, as the study may not have been sufficiently powered to detect small effects. As participants were recruited via social networks and existing contacts, all of them where from the surrounding areas, which may have introduced selection bias and limited the representiveness of a wide cycling population. In addition, the number of races done by each participant is diverse; some participants did more than 30 races, whilst others did less than 10. Those cyclists who did less races had less opportunities to get better results. An action that could attenuate this limitation could be the eligibility criteria to be part of the sample, although it would have been even lower. Another possible limitation of this study was that weekly volume was collected from the files that each cyclist uploaded from their own devices, admitting that its calculation may have small variations. Finally, the incremental test aimed also to find the MFO; therefore, some tests exceeded 30 minutes which means that VO_{2max}, PPO and PPO·kg^{-1} may have been underestimated since the duration of tests that estimate this parameters should last between 8 to 12 minutes (Jamnick et al., 2018).

Conclusions

Training volume in highly trained cyclists is a key determinant of aerobic performance in VO_{2max}, PPO and PPO·kg^{-1}, whereas MFO appears to be independent from training hours. Elite and U23 cyclists had better values in VO_{2max} and PPO·kg^{-1} than M30 cyclists, highlighting the influence of category, training status and race characteristics. No difference was found between categories in PPO since it only considers aerobic fitness without body composition nor MFO which seems to be preserved independently of the category. The absence of association between the physiological parameters analyzed and race performance demonstrates the multifactorial nature of racing success.

From a practical perspective, this study may offer a practical insight for those coaches, team directors and practitioners who seek to understand how training and physiological parameters are in amateur cyclists. The positive associations observed between weekly training hours and VO_{2max}, PPO and PPO·kg^{-1}, suggest that training volume should be considered a relevant component in the training periodization of amateur cyclists. However, coaches and physical trainers should integrate volume with an appropriate and individual periodization of intensity distribution, as training volume only explained a moderate proportion of the variance. Moreover, the absence of associations between the physiological parameters analyzed and race performance highlights that laboratory tests and metrics should not be treated in isolation when evaluating competition success. Tactical decisions, team roles, psychological factors and race types play an important role in race outcomes. Younger cyclists may present greater potential development, although Elite cyclists demonstrate comparable physiological capacities combined with competitive experience. Therefore, talent identification from PRO teams ought to be considered through a multidimensional approach, integrating physiological assessments, training characteristics and competitive experience rather than relying solely on single performance indicators.

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