International Journal of Sports Physiology and Performance, (Ahead of Print)
https://doi.org/10.1123/ijspp.2021-0256

First Published Online: Jan. 6, 2022

Human Kinetics
ORIGINAL INVESTIGATION

Cross-Sectional Differences in Race Demands Between Junior, Under 23, and Professional Road Cyclists

Gabriele Gallo, Peter Leo, Manuel Mateo-March, Andrea Giorgi, Emanuela Faelli, Piero Ruggeri, Iñigo Mujika, and Luca Filipas

***Purpose**:* To compare the race demands of junior (JUN), under 23 (U23), and professional (PRO) road cyclists. ***Methods**:* Thirty male cyclists, divided into 3 age-related categories (JUN, n = 10; U23, n = 10; and PRO, n = 10), participated in this study. Race data collected during the 2019 competitive season were retrospectively analyzed for race characteristics, external, and internal competition load. ***Results**:* Higher annual and per race duration, distance, elevation gain, Edward's training impulse, total work, and work per hour were observed in PRO versus U23 and JUN, and U23 versus JUN ($P < .01$). PRO and U23 recorded higher mean maximal power (RPOs) between 5 and 180 minutes compared with JUN ($P < .01$). Edward's training impulse per hour was higher in JUN than PRO and U23 ($P < .01$). Accordingly, JUN spent a higher percentage of racing time in high internal intensity zones compared with U23 and PRO, while these 2 categories spent more time at low internal intensity zones ($P < .01$). ***Conclusions**:* JUN races were shorter and included less elevation gain per distance unit compared to U23 and PRO races, but more internally demanding. JUN produced less power output in the moderate-, heavy-, and severe-intensity exercise domains compared with U23 and PRO (RPOs: 5–180 min). U23 and PRO races presented similar work demands per hour and RPOs, but PRO races were longer than U23.

***Keywords**:* youth cycling, cycling competitions, race characteristics, internal load, external load

International road cycling racing, ruled by the Union Cycliste Internationale (UCI), includes 3 age-related categories which follow a race calendar culminating with world championships: junior (JUN; 17–18 y), under 23 (U23; 19–23 y), and professional (PRO; >23 y).

Previous studies have already reported anthropometrical and laboratory-based physiological characteristics of these 3 categories (JUN,[1,2] U23,[3] and PRO[4–6]), but the widespread use of mobile heart rate (HR) monitors and portable mechanical power meters permits nowadays to capture field data for a deeper understanding of the requirements of road cycling competition.[7] Indeed, power output (PO) and HR-derived parameters provide insights about the external (the objective measure of the work that an athlete completes) and internal (the individual psychophysiological response to cope with the external load) demands of exercise.[8,9] A number of studies have analyzed the external and internal demands of professional road races,[10,11] comparing men and women events,[12] professional men races with different competitive levels,[13] and altimetric profiles.[14] On the other hand, only one study described the racing demands of youth cycling categories. In that study, however, Rodríguez-Marroyo et al[15] reported only internal demands of JUN and in under 17 cyclists.

Gallo, Faelli, and Ruggeri are with the Dept of Experimental Medicine, Section of Human Physiology and the Centro Polifunzionale di Scienze Motorie, University of Genoa, Genoa, Italy. Leo is with the Dept of Sports Science, University of Innsbruck, Tirol, Austria. Mateo-March is with the Spanish Cycling Federation, Madrid, Spain. Giorgi is with the Androni Giocattoli–Sidermec Professional Cycling Team and the Unità operativa complessa Recupero e rieducazione funzionale, Azienda USL Toscana Sud-Est, Italy. Mujika is with the Dept of Physiology, Faculty of Medicine and Nursing, University of the Basque Country, Leioa, Basque Country, and the Exercise Science Laboratory, School of Kinesiology, Faculty of Medicine, Universidad Finis Terrae, Santiago, Chile. Filipas is with the Dept of Biomedical Sciences for Health, Università degli Studi di Milano, Milan, Italy, and the Dept of Endocrinology, Nutrition and Metabolic Diseases, IRCCS MultiMedica, Milan, Italy. Filipas (luca.filipas@unimi.it) is corresponding author.

To the best of our knowledge, a cross-sectional analysis of external and internal race demands in JUN, U23, and PRO has not yet been carried out. Possible differences between the competition demands in the different categories could underline different physical attributes required to compete and succeed in different age categories, which in turn could negatively influence talent selection based only on race performance (eg, not selecting JUN unsuccessful cyclists who have the physical attributes to be successful in the PRO category). Regarding this point, Menaspà et al[16] reported that JUN selected for the national team mainly included flat specialists. The authors suggested this could be due to the lower elevation gain typical of JUN compared with PRO races, which penalizes climbers.

In addition, even if coaches traditionally attempt to modulate both volume and intensity of training considering the maturation level of the cyclists during development stages, comparing different age categories, actual race demands could give further responses on how to adjust training strategies for competing in different road cycling categories.

Therefore, the aim of this study was to compare the external and internal race demands of the 3 UCI age-limited road cycling categories: JUN, U23, and PRO. Our hypothesis is that the progressive increase in distance per race through categories leads to substantial differences in external and internal demands between categories and that JUN races includes less elevation gain per distance unit compared with both U23 and PRO races, which might penalize JUN climbers.

Methods

Participants

Thirty male cyclists, divided into the 3 age-related categories ruled by the UCI (JUN, n = 10; U23, n = 10; and PRO, n = 10) participated in this study. Anthropometric characteristics of the participants are reported in Table 1. Each category cohort was composed of cyclists riding for the same team. The competitive level of all 3 groups was high within their category: the JUN group won the Italian national team seasonal ranking and included a rider who won the silver medal at UCI Road World Championships; 5 out of 10 U23 cyclists became professional within 2 seasons after the one considered in the present study (ie, within 2021); and the PRO group ranked in the top 10 in the World Tour team seasonal ranking.

Considering their cycling status, all participants can be classified as "performance level 5" (training frequency per week > 5, cycling experience > 5 y, and training hours per week > 10) according to the guidelines of De Pauw et al.[17]

The study design and procedures were approved by the research ethics committee of the Università degli Studi di Milano and followed the ethical principles for medical research involving human participants set by the World Medical Association Declaration of Helsinki. Participants were provided with written instructions outlining the procedures and risks associated with the study and gave informed written consent.

Experimental Design

For each category, the 2019 season was taken into consideration for data analysis. Race characteristics, HR, and PO data were collected during races using a cycling performance software analyzer (WKO5; TrainingPeaks LLC, Boulder, CO). All data were visually checked for erroneous data, and incomplete data files due to technological issues (eg, flat battery of a power meter) were removed when necessary. If one of the 2 main variables (ie, PO, HR) was missing for a given race but no erroneous data were present within the given session, the data set was still analyzed using the available variables. For each category, we took into consideration all races, not distinguishing between race typologies (ie, stage races, 1-d races, etc), because JUN ride almost all 1-day races.

Race Characteristics

Duration, distance, and elevation gain were recorded using 2 different power meter head units: JUN and U23 used Garmin Edge 520, while PRO used Garmin Edge 810 (Garmin, Schaffhausen, Switzerland). It has been previously shown that the analyzed variables were relatively consistent within devices of this brand if, as in our case, the same setting was used (ie, elevation correction).[18] In addition, the total annual number of races was also recorded (race days). The percentage of the annual exercise duration spent in races (race percentage) and the elevation gain per distance ratio were also calculated.

Table 1 Anthropometric Characteristics of the Participants, Divided by Age Category

	JUN	U23	PRO	*P*	ES
Age, y	17.2 (0.5)	19.7 (0.3)*	27.7 (1.4)*#	<.001	0.776
Height, cm	179 (2)	181 (2)	182 (2)	.860	0.011
Weight, kg	65.8 (6.4)	65.1 (5.2)	66.7 (7.0)	.519	0.049
BMI, $kg \cdot m^{-2}$	20.5 (0.8)	19.9 (1.2)	20.0 (1.4)	.527	0.048

Abbreviations: BMI, body mass index; ES, effect size; JUN, junior; PRO, professional; U23, under 23. Note: Data are presented as mean (SD).
*Significantly different from JUN. #Significantly different from U23.

Race External Demands

Race external demands were calculated based on power data collected with portable power meters: JUN, Garmin Vector 3 (Garmin); U23, SRAM RED eTap (SRAM RED, Spearfish, South Dakota); and PRO, Power2max (Saxonar GmbH, Waldhufen, Germany). The accuracy of these instruments in power calculation was previously verified and validated.[19] All riders were informed about the importance of the zero calibration of power meters and were instructed to do the zero calibration before every ride.

Annual total work was derived summing the total work accumulated during each race, calculated with the following formula:

$$\text{Total work (kj)} = \text{Power output (W)} \times \text{duration (s)}/1000.$$

Race external intensity was calculated using the total work per duration ratio. To distinguish the different contribution of race days and durations on annual total work, the total work per race days ratio was calculated. Record power profiles were also calculated following Pinot and Grappe's method,[20] as the highest absolute (in watts) and relative (in watts) mean recorded POs (RPO) over the corresponding time durations, considering 13 time frames (1, 5, 30, 60 s and 5, 10, 20, 30, 45, 60, 120, 180, 240 min). In addition, the percentage of total race time spent at different PO bands was calculated using steps of 0.75 $W \cdot kg^{-1}$ ranging from <0.75 to >7.50 $W \cdot kg^{-1}$, as already done in previous studies.[12,21]

Race Internal Demands

Race internal demands were assessed based on HR data collected with portable HR monitors connected with a chest strap (Garmin).

Race internal load was calculated using Edwards' training impulse (eTRIMP).[22] eTRIMP was calculated based on time spent in the 5 predefined HR zones multiplied by a zone-specific arbitrary weighting factor: zone 1, 50% to 59% HR_{peak} (multiplication factor 1); zone 2, 60% to 69% HR_{peak} (factor 2); zone 3, 70% to 79% HR_{peak} (factor 3); zone 4, 80% to 89% HR_{peak} (factor 4); and zone 5, 90% to 100% HR_{peak} (factor 5). HR_{peak} was defined as the highest HR recorded during the season. Race internal intensity was calculated using the eTRIMP per duration ratio. To distinguish the different contribution of race days and durations on annual eTRIMP, eTRIMP per race days ratio was also calculated. The same 5 HR zones used in the eTRIMP calculation were used to report the race internal intensity distribution expressed as percentage of time spent in each intensity zone.

Statistical Analysis

All data are presented as mean (SD). For each variable, outliers which were more than 3 SDs from the mean of the respective group were excluded from further analysis. For all the variables analyzed per race, the total annual of each variable was obtained from WKO for each cyclist and then, divided by the number of races the cyclist completed. Assumptions of statistical tests such as normal distribution and sphericity of data were checked with Shapiro–Wilk and Mauchly tests, respectively. Greenhouse–Geisser correction to the degrees of freedom was applied when violation of sphericity was present. To compare the mean of all variables between the 3 groups, 1-way analysis of variance was performed when normality assumption was met, otherwise a Kruskal–Wallis *H* test was performed. Depending on whether assumption of homogeneity of variance was met or not (Levene test), Bonferroni or Games–Howell post hoc test was performed, respectively. Significance was set at .05 (2-tailed) for all analyses. Effect sizes (ESs) for 1-way analysis of variance are reported as partial eta squared and for Kruskal–Wallis *H* test as epsilon squared, using the small (<0.13), medium (0.13–0.25), and large (>0.25) interpretation for ES.[23] Data analysis was conducted using the statistical package for the social sciences (version 26; SPSS Inc, Chicago, IL).

Results

Race Characteristics

Race characteristics for the 3 age categories are reported in Table 2. There were significant differences with large effects among the 3 groups for all the parameters considered. Post hoc tests showed that annual duration, duration per race, annual distance, distance per race, annual elevation gain, and elevation gain per race were higher in PRO compared with U23 and JUN and in U23 compared with JUN ($P < .01$). Race days and race percentage were higher in PRO compared with U23 and JUN ($P < .001$) but did not differ between U23 and JUN. Elevation gain per distance was higher in PRO and U23 compared with JUN ($P < .001$) but did not differ between PRO and U23.

Race External Demands

Race external demands are presented in Figure 1. There were significant differences with large effects among the 3 groups for annual total work, work per hour, and work per race ($P < .001$, ES = 0.86–0.89). Percentage time spent at low PO intensity (1.51–3.00 W·kg^{-1}) was higher in JUN compared with U23 ($P < .05$, ES = 0.29–0.37), but did not differ between U23 and PRO or JUN and PRO. Percentage time spent within the 3.76 to 4.50 W·kg^{-1} band was lower in JUN compared with PRO ($P < .05$, ES = 0.29), but did not differ between JUN and U23 or U23 and PRO. Percentage time spent between 4.51 and 6.00 W·kg^{-1} was lower in JUN compared both to PRO and U23 ($P < .01$, ES = 0.40–0.60), but did not differ between U23 and PRO. Percentage time spent at the higher end of the power bands (>7.50 W·kg^{-1}) was higher in JUN ($P < .01$, ES = 0.57) compared with U23 and PRO, but did not differ between U23 and PRO.

Record PO profiles showed significant differences with large effects among the 3 groups for both absolute and relative RPO-5 minutes, RPO-10 minutes, RPO-20 minutes, RPO-30 minutes, RPO-45 minutes, RPO-60 minutes, RPO-120 minutes, and RPO-180 minutes ($P < .01$; ES =0.29–0.61; Figure 2).

Race Internal Demands

Race internal demands are presented in Figure 3. There were significant differences among the 3 groups for annual eTRIMP and eTRIMP per hour ($P < .01$, ES = 0.39–0.85), while eTRIMP per race did not differ between groups. Race internal intensity distribution showed significant differences among the 3 groups for the percentage of time spent in all the intensity zones ($P < .01$, ES = 0.40–0.74).

Discussion

To the best of our knowledge, this is the first study that reported cross-sectional differences in race characteristics and external and internal race demands of the 3 UCI age-limited road cycling categories: JUN, U23, and PRO. In line with our hypothesis, the results highlighted large differences among categories for general race characteristics, external, and internal race demands.

Race Characteristics

The annual race distance, duration, and elevation gain increased progressively across the 3 age categories. This could be due to the increase in difficulty of races from JUN to PRO, together with a higher number of race days in PRO compared with JUN and U23. The progressive increase of the duration per race, distance per race, and elevation gain per race is a natural consequence of length restrictions established by national and international rules for each category. Concerning race days, PRO competed in approximately twice as many races (77 [6]) than U23 (2 [11]) and JUN (36 [7]) cyclists. Furthermore, PRO spent a higher percentage of the annual cycling volume in races compared to youth categories. Hence, when planning the annual periodization, practitioners should be aware that an appropriate programming of a racing schedule is far more important in professional than in youth categories, to appropriately find the right balance between training and/or competition load and recovery. This approach could be helpful to achieve performance peaks in the high-priority races.

In line with our initial hypothesis, elevation gain per distance was lower in JUN compared with both U23 and PRO. This finding could suggest that climbers (ie, riders with higher relative PO on medium and long-duration uphill efforts[4,5]) might have less opportunity to emerge than flat terrain specialists (ie, cyclists with higher absolute PO on short and medium-duration efforts[4,5]) in JUN compared with U23 and PRO races. Accordingly, Menaspà et al[16]

Table 2 Race Characteristics of the 3 Age Categories

	JUN	U23	PRO	*P*	ES
Race days, n	36 (7)	42 (11)	77 (6)*,#	<.001	0.831
Annual duration, h	86 (20)	129 (33)*	303 (27)*,#	<.001	0.926
Race percentage, %	16.9 (0.8)	18.2 (3.3)	33.5 (2.6)*,#	<.001	0.903
Duration per race, h	2.4 (0.2)	3.1 (0.3)*	3.9 (0.2)*,#	<.001	0.882
Annual distance, km	3300 (815)	4920 (1345)*	11,569 (981)*,#	<.001	0.919
Distance per race, km	94 (3)	124 (10)	150 (7)*,#	<.001	0.761
Annual elevation gain, km	18 (5)	57 (16)*	145 (19)*,#	<.001	0.937
Elevation gain per race, m	520 (57)	1387 (100)*	1870 (63)*,#	<.001	0.876
Elevation gain per distance, m·km^{-1}	5.9 (0.3)	11.6 (0.4)*	12.5 (0.3)*	<.001	0.923

Abbreviations: ES, effect size; JUN, junior; PRO, professional; U23, under 23. Note: Data are presented as mean (SD).
*Significantly different from JUN ($P < .05$). #Significantly different from U23 ($P < .05$).

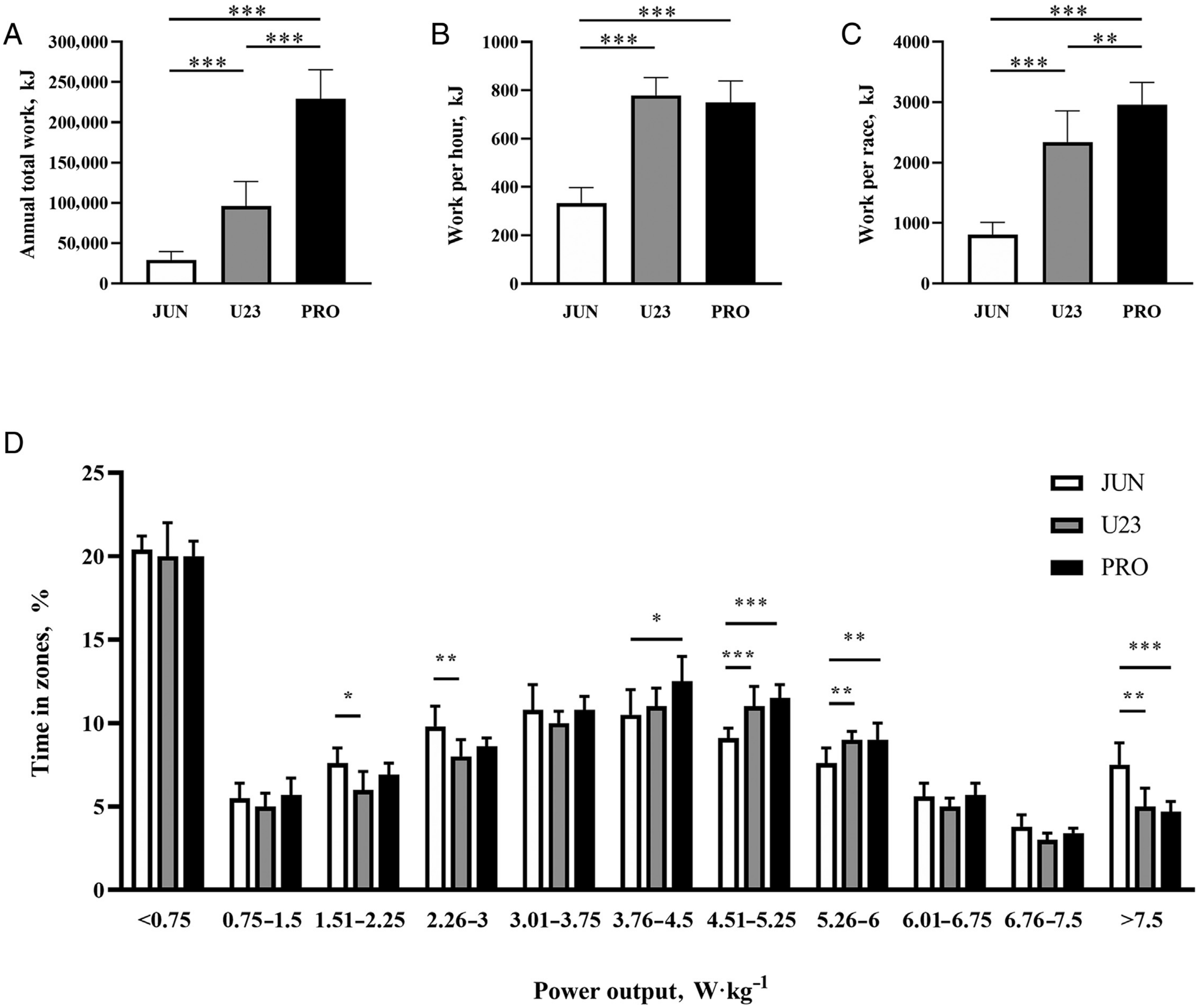

Figure 1 — Race external demands of JUN, U23, and PRO cyclists. (A) Annual total work, (B) total work per hour, (C) total work per race, and (D) power output distribution as percentage of racing time spent in different power bands. JUN indicates junior; PRO, professional; U23, under 23. Significant difference between the groups (**P* < .05, ***P* < .01, and ****P* < .001).

found that JUN cyclists selected by their national team for international races possess superior level-ground abilities (ie, body mass, absolute peak oxygen uptake, oxygen uptake at the respiratory compensation point, and ventilatory threshold) than riders who were not selected, suggesting that successful JUN riders are those more competitive in flat races. As JUN race characteristics are not tailored for their performance capacities, these riders might show their true potential only in mountainous races of U23 and PRO categories. Therefore, talent scouts and practitioners should evaluate UN cyclists with also physiological testing and not only by race performance, in order to include this type of riders in the athletes selections in the superior age categories (ie, from JUN to U23 and from U23 to PRO) even if the race results are not as promising as other riders.

Race External Demands

The results of the present study showed that annual total work and work per race increase progressively across the 3 age categories. Total work per hour did not differ between U23 and PRO, but was lower in JUN. Such lower external intensity despite a lower duration per race indicates that JUN riders are not able to produce the same PO as U23 and PRO cyclists. Although JUN showed similar short-duration RPOs (1–60 s) compared with U23 and PRO, they recorded lower long-duration RPOs (5–180 min). Hence, according to the PO spent at different exercise intensity domains,[20] the lower external intensity expressed in JUN races might be due to the JUN cyclists' lower ability to produce power in the moderate, heavy, and severe exercise intensity zones compared with their U23 and PRO counterparts.

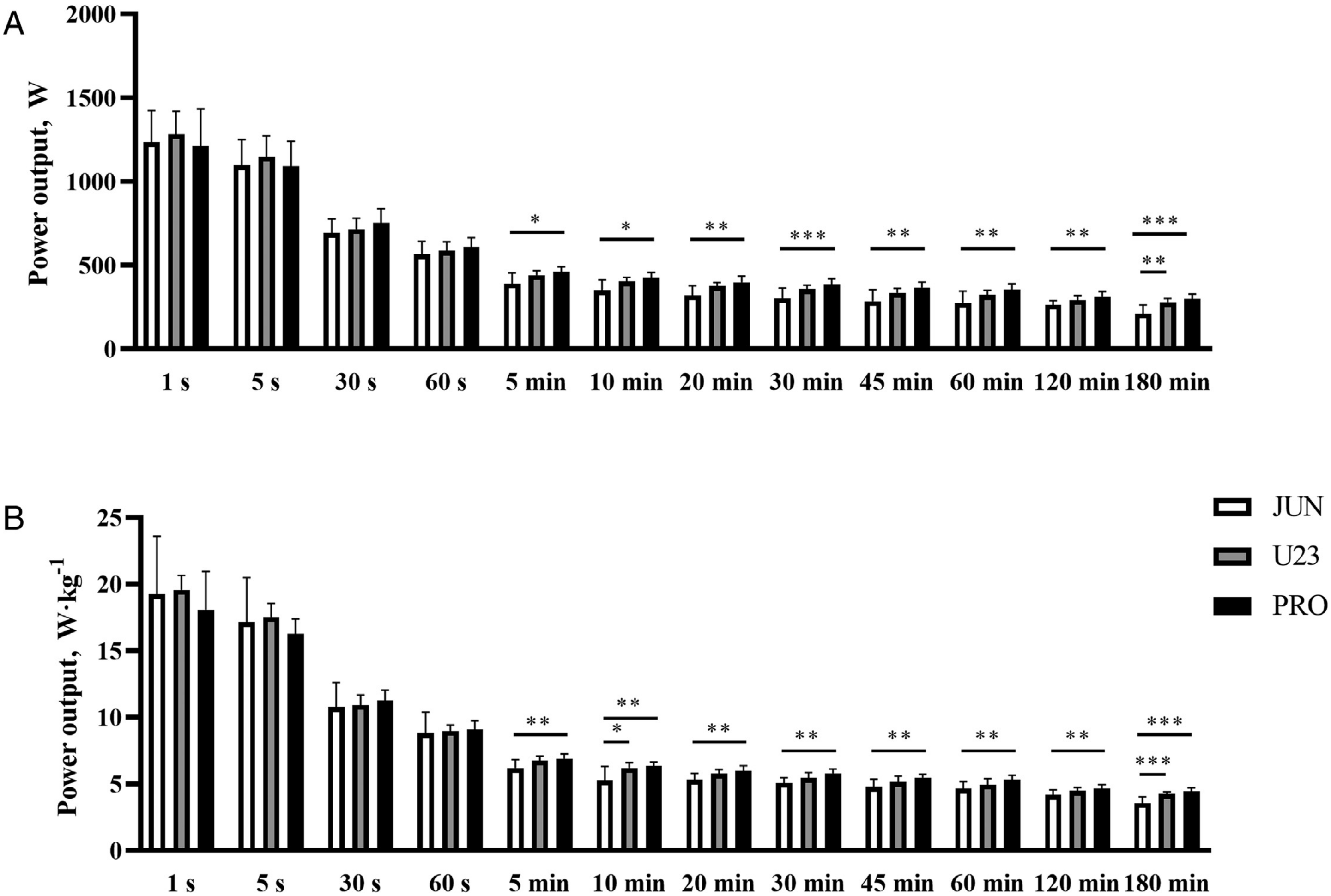

Figure 2 — Absolute (A) and relative (B) mean recorded power outputs over the corresponding time durations considering 13 time frames (1, 5, 30, 60 s and 5, 10, 20, 30, 45, 60, 120, 180, 240 min). JUN indicates junior; PRO, professional; U23, under 23. Significant difference between the groups (**P* < .05, ***P* < .01, and ****P* < .001).

When looking at PO intensity distribution, a rightward shift between 1.51 and 6.00 $W \cdot kg^{-1}$ for U23 and PRO compared to JUN was observed. As the range 1.51 to 6.00 $W \cdot kg^{-1}$ approximately represent the moderate-, heavy-, and severe-intensity exercise domains, the power intensity distribution seems to confirm a higher capacity to produce PO in these exercise intensity domains in PRO and U23 compared with JUN. On the other hand, the higher percentage racing time spent at PO > 7.50 $W \cdot kg^{-1}$ in JUN compared to both U23 and PRO could be a consequence of a similar capacity to produce PO in the force–velocity exercise intensity domain across the 3 categories (confirmed by similar short durations RPOs [1 s to 1–60 s]), combined with JUN's lower duration per race respect to U23 and PRO. Very interestingly, PRO completed more total work per race than U23, but these 2 categories did not differ for the external intensity (ie, total work per hour), and for both absolute and relative RPOs. Thus, PRO and U23 races differ only in duration and not external intensity: PRO cyclists do not produce higher POs than U23, but they produce the same PO for longer durations than U23 cyclists. Accordingly, Leo et al[24] showed that during a 5-day cycling multistage race including both PRO and U23 teams, absolute and relative RPOs were not different between professional and U23 cyclists but, interestingly, professional cyclists showed higher relative RPOs after a certain amount of work (1000–3000 kJ) than U23 cyclists. From this perspective, our findings could suggest that fatigue resistance (ie, the ability to decrease the PO as little as possible after a prior amount of exercise) could be a peculiar feature that differentiates PRO from U23 cyclists. Interestingly, in a very recent study, Van Erp et al[25] also showed that fatigue resistance is an important parameter for success even within the PRO category.

Race Internal Demands

eTRIMP per race was similar between the 3 categories, but volume and internal intensity were combined in different ways across the 3 categories. Specifically, in contributing to the total eTRIMP per race, intensity (ie, eTRIMP per hour) played a major role in JUN (ie, higher eTRIMP per hour in JUN compared to both U23 and PRO); conversely, volume (ie, duration per race) played a more important role in the latter 2 categories respect to JUN. Accordingly, the HR intensity distribution showed that JUN spent much more time at high-intensity zones (ie, 80%–89% and 90%–100% HR_{peak}), while U23 and PRO accumulated a higher percentage of racing time in lower intensity zones (ie, 50%–59%, 60%–69%, and 70%–79% HR_{peak}).

Hence, it seems clear that JUN compensate for the shorter duration of their races with a higher internal intensity, similarly to

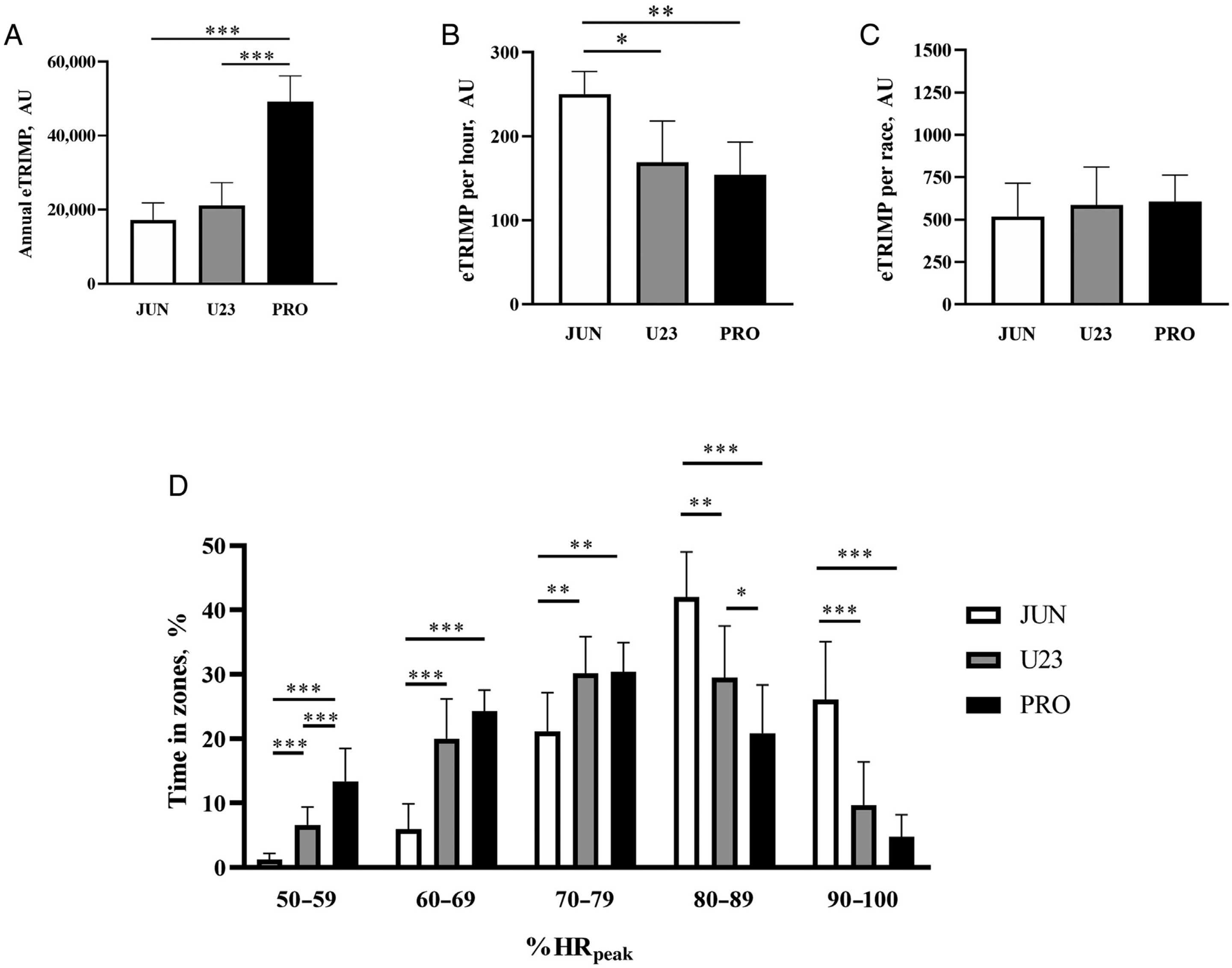

Figure 3 — Race internal demands of JUN, U23, and PRO cyclists. (A) Annual eTRIMP, (B) eTRIMP per hour, (C) eTRIMP per race, and (D) HR distribution as percentage of racing time spent in different heart rate zones. HR indicates heart rate; JUN, junior; PRO, professional; eTRIMP, Edwards training impulse; U23, under 23. Significant difference between the groups (*$P<.05$, **$P<.01$, ***$P<.001$).

what Sanders et al[12] observed for professional women compared with their men counterparts.

The PRO races were longer, and a similar or higher percentage of time was accumulated in low-intensity HR zones compared with U23 and JUN. This suggests that "low-intensity durability" (ie, preserving the capacity to produce PO after prior long-duration moderate-intensity exercise) as a specific facet of fatigue resistance could be a peculiar feature required to become a PRO cyclist. In addition to the lower duration per race, another factor which might contribute to the higher intensity observed in JUN races could be that, in this category, teamwork dynamics are less present in comparison with U23 and PRO races. This means that traditionally no teams control the race by pulling the peloton, allowing other riders to follow a constant pace taking advantages from the draft.[26] At the opposite, in JUN races, there are more individual attacks, which might contribute to the higher mean intensity observed.

Limitations

The main limitation of this study is the low sample size and that all athletes for each category are part of only one team. Including more than one team for each category could eliminate the influence of team racing tactics on external and internal demands. However, such an approach is not easily feasible since it is difficult to aggregate data from high-level teams competing against each other within the same age category due to possible conflicts of interest and data liability rules. In addition, the calculation of HR to derive eTRIMP and HR intensity distribution has been performed only on an annual basis using seasonal HR_{peak}. This approach could have led to suboptimal accuracy, as HR_{peak} could change day-to-day due to fatigue state.[27] Ideally, HR should have been updated more frequently across the season using standardized tests. However, during the time of the analysis, not all the 3 cohorts (JUN, U23, and PRO) performed controlled exercise testing using the same protocol, making such approach not feasible.

Another possible limitation of this study was that PO data were collected with different power meter brands. Even if the accuracy of these instruments in power calculation was previously verified and validated,[19] there could be a difference between all the power meter brands used.

Practical Applications

The differences we found in race characteristics and physical external and internal demands between JUN, U23, and PRO could lead to useful practical implications for coaches and practitioners. First, concerning talent identification, our results demonstrated that climbers are less likely to show their full potential in JUN races, due to the lower elevation gain per distance observed in JUN compared with U23 and PRO. Practitioners should be careful when selecting riders from the youth categories, considering that climbers are disadvantaged by race characteristics at JUN level.

Finally, when selecting U23 cyclists to become PRO cyclists, fatigue resistance should be taken into consideration, as PRO and U23 PO did not differ during races, but in PRO races the same PO is maintained for longer durations.

Regarding training strategies, JUN could potentially benefit from more high-intensity training, whereas U23 and PRO could benefit from more volume accumulated at moderate intensities. On the other hand, the results of this study could also be seen as an indication for coaches on how to set their training programs in a talent development perspective. In this sense, at the JUN level, it could be important from a long-term perspective not to chase the physical demands of the current age category (ie, fostering high-intensity training), but to focus more on athlete long-term development by targeting the requirements of the U23 and PRO categories (ie, fostering high-volume training). However, even if training at race-specific intensities is a concept which has been widely used by coaches during the last decades, it is still debated if training intensity specificity is a fundamental requirement in endurance sports context.[28]

Conclusions

The JUN cycling races were shorter, more intense, and included less elevation gain for distance unit compared to U23 and PRO races, suggesting that JUN climbers are likely to show their true potential only in mountainous races of U23 and PRO categories. During races, JUN produced less PO in the moderate-, heavy-, and severe-intensity exercise domains compared with U23 and PRO (RPOs: 5–180 min). Work per hour and RPOs were similar in U23 and PRO races, but PRO races had longer durations than U23, suggesting that fatigue resistance is a feature required of road cyclists moving up from the U23 to PRO category.

References

1. Menaspà P, Rampinini E, Bosio A, Carlomagno D, Riggio M, Sassi A. Physiological and anthropometric characteristics of junior cyclists of different specialties and performance levels. *Scand J Med Sci Sport*. 2012;22(3):392–398. doi:10.1111/j.1600-0838.2010.01168.x
2. Gallo G, Filipas L, Tornaghi M, et al. Thresholds power profiles and performance in youth road cycling. *Int J Sports Physiol Perform*. 2021;16(7):1049. doi:10.1123/ijspp.2020-0579
3. Sallet P, Mathieu R, Fenech G, Baverel G. Physiological differences of elite and professional road cyclists related to competition level and rider specialization. *J Sports Med Phys Fitness*. 2006;46(3):361. PubMed ID: 16998438
4. Padilla S, Mujika I, Cuesta G, Goiriena JJ. Level ground and uphill cycling ability in professional road cycling. *Med Sci Sports Exerc*. 1999;31(6):878–885. doi:10.1097/00005768-199906000-00017
5. Mujika I, Padilla S. Physiological and performance characteristics of male professional road cyclists. *Sports Med*. 2001;31(7):479–487. doi:10.2165/00007256-200131070-00003
6. Giorgi A, Vicini M, Pollastri L, et al. Bioimpedance patterns and bioelectrical impedance vector analysis (BIVA) of road cyclists. *J Sports Sci*. 2018;36(22):2608–2613. PubMed ID: 29708859 doi:10.1080/02640414.2018.1470597
7. Passfield L, Hopker JG, Jobson S, Friel D, Zabala M. Knowledge is power: issues of measuring training and performance in cycling. *J Sports Sci*. 2017;35(14):1426–1434. PubMed ID: 27686573 doi:10.1080/02640414.2016.1215504
8. Mujika I. Quantification of training and competition loads in endurance sports: methods and applications. *Int J Sports Physiol Perform*. 2017;12(Suppl 2):S29–S217. doi:10.1123/ijspp.7.2.186
9. Impellizzeri FM, Marcora SM, Coutts AJ. Internal and external training load: 15 years on. *Int J Sports Physiol Perform*. 2019;14(2):270–273. PubMed ID: 30614348 doi:10.1123/ijspp.2018-0935
10. Vogt S, Heinrich L, Schumacher YO, et al. Power output during stage racing in professional road cycling. *Med Sci Sports Exerc*. 2006;38(1):147–151. PubMed ID: 16394967 doi:10.1249/01.mss.0000183196.63081.6a
11. Sanders D, van Erp T. The physical demands and power profile of professional men's cycling races: an updated review. *Int J Sports Physiol Perform*. 2021;1:1–10. doi:10.1123/ijspp.2020-0508
12. Sanders D, van Erp T, de Koning JJ. Intensity and load characteristics of professional road cycling: differences between men's and women's races. *Int J Sports Physiol Perform*. 2019;14(3):296. doi:10.1123/ijspp.2018-0190
13. van Erp T, Sanders D. Demands of professional cycling races: influence of race category and result. *Eur J Sport Sci*. 2020;21(5):666–677. PubMed ID: 32584197 doi:10.1080/17461391.2020.1788651
14. Sanders D, Heijboer M. Physical demands and power profile of different stage types within a cycling grand tour. *Eur J Sport Sci*. 2019;19(6):736–744. PubMed ID: 30589390 doi:10.1080/17461391.2018.1554706
15. Rodríguez-Marroyo JA, Pernía R, Cejuela R, García-López J, Llopis J, Villa JG. Exercise intensity and load during different races in youth and junior cyclists. *J Strength Cond Res*. 2011;25(2):511–519. PubMed ID: 20224447 doi:10.1519/JSC.0b013e3181bf4426
16. Menaspà P, Sassi A, Impellizzeri FM. Aerobic fitness variables do not predict the professional career of young cyclists. *Med Sci Sports Exerc*. 2010;42(4):805–812. PubMed ID: 19952851 doi:10.1249/MSS.0b013e3181ba99bc
17. De Pauw K, Roelands B, Cheung SS, De Geus B, Rietjens G, Meeusen R. Guidelines to classify subject groups in sport-science research. *Int J Sports Physiol Perform*. 2013;8(2):111–122. PubMed ID: 23428482 doi:10.1123/ijspp.8.2.111
18. Menaspà P, Impellizzeri FM, Haakonssen EC, Martin DT, Abbiss CR. Consistency of commercial devices for measuring elevation gain. *Int J Sports Physiol Perform*. 2014;9(5):884. doi:10.1123/ijspp.2013-0232
19. Maier T, Schmid L, Müller B, Steiner T, Wehrlin JP. Accuracy of cycling power meters against a mathematical model of treadmill cycling. *Int J Sports Med*. 2017;38(6):456–461. doi:10.1055/s-0043-102945

20. Pinot J, Grappe F. The record power profile to assess performance in elite cyclists. *Int J Sports Med*. 2011;32(11):839–844. PubMed ID: 22052032 doi:10.1055/s-0031-1279773
21. Menaspà P, Sias M, Bates G, La Torre A. Demands of world cup competitions in elite women's road cycling. *Int J Sports Physiol Perform*. 2017;12(10):1293–1296. PubMed ID: 28253040 doi:10.1123/ijspp.2016-0588
22. Edwards S. The heart rate monitor book. *Med Sci Sport Exerc*. 1994;26(5):647. doi:10.1249/00005768-199405000-00020
23. Bakeman R. Recommended effect size statistics for repeated measures designs. *Behav Res Methods*. 2005;37(3):379–384. PubMed ID: 16405133 doi:10.3758/BF03192707
24. Leo PA, Giorgi D, Spragg J, Mujika I, Lawley JS. Workload characteristics and race performance of U23 and elite cyclists during an UCI 2. Pro multistage race (Tour of the Alps). *J Sci Cycl*. 2020; 9:4–6. https://www.jsc-journal.com/index.php/JSC/article/view/552
25. van Erp T, Sanders D, Lamberts RP. Maintaining power output with accumulating levels of work done is a key determinant for success in professional cycling. *Med Sci Sport Exerc*. 2021. doi:10.1249/mss.0000000000002656
26. Ouvrard T, Groslambert A, Ravier G, Grosprêtre S, Gimenez P, Grappe F. Mechanisms of performance improvements due to a leading teammate during uphill cycling. *Int J Sports Physiol Perform*. 2018;13(9):1215–1222. PubMed ID: 29651888 doi:10.1123/ijspp.2017-0878
27. Sanders D, Heijboer M, Hesselink MKC, Myers T, Akubat I. Analysing a cycling grand tour: can we monitor fatigue with intensity or load ratios? *J Sports Sci*. 2018;36(12):1385–1391. PubMed ID: 29016241 doi:10.1080/02640414.2017.1388669
28. Laursen PB. Training for intense exercise performance: high-intensity or high-volume training? *Scand J Med Sci Sport*. 2010;20:1–10. doi:10.1111/j.1600-0838.2010.01184.x