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ORIGINAL INVESTIGATION

The Record Power Profile of Male Professional Cyclists: Normative Values Obtained From a Large Database

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Purpose: To present normative data for the record power profile of male professional cyclists attending to team categories and riding typologies. ***Methods:*** Power output data registered from 4 professional teams during 8 years (N = 144 cyclists, 129,262 files, and 1062 total seasons [7 (5) per cyclist] corresponding to both training and competition sessions) were analyzed. Cyclists were categorized as ProTeam (n = 46) or WorldTour (n = 98) and as *all-rounders* (n = 65), *time trialists* (n = 11), *climbers* (n = 50), *sprinters* (n = 11), or *general classification contenders* (n = 7). The record power profile was computed as the highest maximum mean power (MMP) value attained for different durations (1 s to 240 min) in both relative ($W \cdot kg^{-1}$) and absolute units (W). ***Results:*** Significant differences between ProTeam and WorldTour were found for both relative ($P = .002$) and absolute MMP values ($P = .006$), with WT showing lower relative, but not absolute, MMP values at shorter durations (30–60 s). However, higher relative and absolute MMP values were recorded for very short- (1 s) and long-duration efforts (60 and 240 min for relative MMP values and ≥5 min for absolute ones). Differences were also found regarding cyclists' typologies for both relative and absolute MMP values ($P < .001$ for both), with sprinters presenting the highest relative and absolute MMP values for short-duration efforts (5–30 s) and general classification contenders presenting the highest relative MMP values for longer efforts (1–240 min). ***Conclusions:*** The present results—obtained from the largest cohort of professional cyclists assessed to date—could be used to assess cyclists' capabilities and indicate that the record power profile can differ between cyclists' categories and typologies.

Keywords*:* power output, cycling, men, elite, assessment

Professional road cycling is a highly demanding sport that tests the limits of human endurance performance.[1–3] Cyclists can be classified into different categories depending on their riding typology and performance during different types of races, namely *sprinters* (those who excel on the final bursts of stages), *time trialists* (those who excel in time trials), *climbers* (those who excel in high mountain ascents), and *all-rounders* (those who do not excel in high mountains or time trials but who achieve good results in mixed stages). Apart from these categories, there are some exceptional riders who excel in all stage types and consequently attain the general classification of a Grand Tour, the *general classification (GC)* contenders.[4–6]

The last few decades have seen the introduction of mobile power meters which have made it possible to monitor cyclists' performances and collect vast amounts of data. The so-called *power profile* (ie, the highest power output [PO; maximum mean power, MMP] achieved for different effort durations by a given cyclist) is commonly used to monitor cyclists' performance.[7] The assessment of this variable outside the laboratory (during actual training or racing), known as the *record power profile* (RPP), has gained much popularity in recent years.[7] Pinot and Grappe[6] defined the RPP as *an identity card of the physical potential of the cyclists*, which could be used to monitor and compare physical capabilities. A number of studies, as per Sanders and Van Erp's review,[8] have reported on the RPP of professional cyclists during races. However, little evidence exists on the highest MMP values reached by professional cyclists in general, and not *only* during competitions as these can be confounded by other factors such as team tactics or fatigue.[9,10] Although some reference values of laboratory-based physiological measures (eg, maximum oxygen consumption [VO_{2max}] or peak power output during an incremental test) have been proposed to characterize *professional* or *world class* cyclists,[1,11,12] no reference values exist for the RPP. Moreover, although the power profile assessed under laboratory conditions has been reported to be sensitive enough to discern between competitive and noncompetitive cyclists,[13] controversy exists regarding the sensitivity of the RPP for monitoring performance changes over a season,[14] or to discern between cyclists of different levels (eg, professionals vs elite) or riding typologies (eg, sprinters, all-rounders, climbers, time-trial specialists and GC contenders).[6]

The aim of this study is to present normative values for the RPP of male professional cyclists based on different categories and typologies.

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Methods

Study Design and Participants

The PO data (~80% and ~20% corresponding to training sessions and competitions, respectively) obtained during 8 years (2013–2021) from 4 cycling teams belonging to 2 different categories

(2 Union Cycliste Internationale [UCI] ProTeam [PT] and 2 UCI WorldTour [WT]) were used for analyses. A total of 129,262 files were obtained from 144 professional cyclists (age 29 [6] y, experience in the professional category 7 [5] y, weight 68 [7] kg, and height 180 [7] cm) during a total of 1062 competition seasons (7 [5] seasons per cyclist). The protocol complied with the Declaration of Helsinki, participants provided written informed consent, and the local Ethics Committee approved the protocol.

Participants, in line with their team designation, were categorized as PT (n = 46) or WT (n = 98). Data from each participant corresponded to a moment when he was competing solely in that specific category, PT or WT—with no participant actually transitioning from one category to the other during the study period. Participants in the WT group included successful cyclists in their category, as ascertained by the following performance history: a total of 2 victories in the GC of a Grand Tour (Giro and Vuelta, respectively); 12 top-3 and 28 top-15 positions, respectively, in the GC of the 3 Grand Tours (Giro, Tour, and Vuelta); >100 victories in individual Grand Tour stages (including sprints, breakaways, mountain ascents, or time trials); and victories in major 1-day races (including the World Championships [both mass start race and individual time trial] and "Monument Classics" such as Milan–San Remo, Paris–Roubaix, Liège-Bastien-Liège, or Flèche Wallonne).

Following categories used in previous studies,[5,8,15] participants were also grouped in accordance to their riding typology (or role within their team) such as: *team work* cyclists or *all-rounders* (n = 65, cyclists who do not especially excel in high mountains or time trials, but can achieve good results in mixed stages), *time trialists* (n = 11, cyclists who are required to perform maximally in time trials), *climbers* (n = 50, cyclists who are required to perform maximally in high mountain ascents), or sprinters (n = 11, cyclists who excel on the final sprint of a stage). We also included a group of *GC contenders* (n = 7, cyclists capable of winning a Grand Tour).

Power Profile

The PO was registered during all possible training sessions and races using 5 power meters (Power2Max Type S Nieder Seifersdorf, Waldhufen, Germany; SRAM Red, Quarq, Spearfish, SD; Shimano Dura-Ace FCRC9100-P, Shimano, Sakai, Japan; SRM, Jülich, Germany; and Pioneer SGY-PM910H2, Pioneer, Kawasaki, Japan). These power meters have previously been used in studies reported on in scientific literature.[16–21] All power meters were factory calibrated at least once per season. A zero offset was performed before each session in accordance with the manufacturers' instructions. PO data were checked for potential spikes using specific software (WKO5 Build 576; TrainingPeaks LLC, Boulder, CO) and manually corrected when necessary. When erroneous outliers were recorded, data were manually corrected using the Data Spike ID and FIX chart, or if the number of outliers was very large, the value was eliminated and the data considered lost.

As described elsewhere,[6] the power profile for each participant was based upon the highest MMP values attained for different effort durations (ie, from 1 s to 240 min). MMP values were expressed both in relative ($W \cdot kg^{-1}$) and absolute units (W).

Statistical Analysis

Data are shown as mean (SD). Normative values are presented as percentiles. Normality was tested using the Kolmogorov–Smirnov test and homoscedasticity was assessed using Levene test. Differences between cyclists' categories and typologies were assessed using a 2-way mixed analysis of variance, with effort duration (MMP) as the within-subject factor and category, or typology, as the between-subject factor. To minimize the risk of statistical type I error, post hoc comparisons were only performed (using the Bonferroni test) when a significant MMP by typology or category interaction effect was found. The magnitude of the differences was assessed through the computation of effect sizes (Cohen *d*) and considered trivial (<0.2), small (<0.6), moderate (<1.2), or large (<2.0).[22] Statistical analyses were conducted using a statistical software package (SPSS 23.0; IBM Corp, Armonk, NY) setting the significance level at $P < .05$.

Results

Normative values for the RPP of male professional cyclists are presented in Table 1.

Cyclists' Category

Participants' descriptive characteristics attending to their category are shown in Table 2. WT cyclists were older and had greater professional experience than PT cyclists ($P < .05$), but no significant differences were found for anthropometrical parameters.

As per Figures 1 and 2, a significant interaction between category and relative ($P = .002$) and absolute MMP values ($P = .006$) was found. WT cyclists attained higher relative MMP values for 1-second efforts ($d = 0.37$) as well as for long duration efforts (60 and 240 min, $d = 0.40$ and 0.45, respectively). In turn, PT attained higher relative MMP values for efforts lasting 30 seconds and 1 minute ($d = 0.62$ and 0.68, respectively). Trivial to small effect sizes ($d = 0.00$–0.36) and nonsignificant differences were found for the remainder of durations. A significant interaction was also observed for absolute MMP values ($P = .006$) with the same trend observed for relative MMP values. Thus, WT cyclists attained higher absolute MMP values than PT values for very short efforts (1 s, $d = 0.51$) as well as for all efforts lasting ≥5 minutes ($d = 0.39$–0.81), whereas PT cyclists did not attain higher absolute MMP values than WT values for any effort duration.

Cyclists' Typology

Table 3 presents participants' descriptive characteristics in relation to their riding typology. Climbers were lighter and shorter than other categories, except for GC contenders, whereas sprinters were heavier than all the remaining categories. GC contenders were lighter and shorter than sprinters and lighter than time trialists, but no differences were noted between climbers and GC contenders, or between all-rounders and time trialists. No differences were found between typologies for age or years of experience.

A significant MMP by typology interaction was found for both relative and absolute values ($P < .001$ for both, as per Figures 3 and 4). GC contenders displayed the highest relative MMP values for all durations ≥1 minute, showing overall higher relative MMP values for long duration efforts (≥5 min) than time trialists ($d = 0.71$–1.96), all-rounders ($d = 1.19$–2.41), and sprinters ($d = 1.14$–7.65), as well as higher MMP values than climbers for efforts lasting 30 ($d = 1.26$) and 60 minutes ($d = 1.32$). As per Figure 3, a trend toward higher MMP values was observed for 20 ($P = .055$, $d = 1.20$) and 120 minutes ($P = .079$, $d = 1.15$) compared with climbers. In addition, Figure 3 shows that climbers presented higher relative MMP values than time trialists, and

Table 1 Normative Data (Percentiles) for Absolute and Relative Maximal Mean Power Values in Male Professional Cyclists (N = 144)

	p10		p25		p50		p75		p90	
	W	W·kg^{-1}	W	W·kg^{-1}	W	W·kg^{-1}	W	W·kg^{-1}	W	W·kg^{-1}
1 s	1111	17.29	1218	18.22	1393	21.08	1623	23.26	1797	24.65
5 s	995	15.71	1091	16.59	1202	17.99	1344	19.78	1529	20.83
10 s	913	14.28	991	15.24	1113	16.59	1240	17.92	1385	18.90
30 s	707	10.88	766	11.71	831	12.62	947	13.36	1040	14.15
1 min	580	8.87	617	9.51	677	10.10	744	10.74	820	11.33
5 min	432	6.52	450	6.75	472	7.06	503	7.34	531	7.65
10 min	399	5.92	414	6.19	435	6.45	455	6.77	481	7.00
20 min	369	5.47	387	5.79	403	6.03	426	6.29	453	6.59
30 min	347	5.10	361	5.36	384	5.71	406	6.02	427	6.24
60 min	310	4.71	329	4.91	350	5.15	368	5.47	398	5.76
120 min	282	4.23	296	4.47	312	4.70	330	4.91	355	5.12
180 min	266	4.00	281	4.27	297	4.45	315	4.64	338	4.84
240 min	252	3.83	268	4.03	284	4.24	298	4.42	325	4.63

Abbreviation: p, percentile.

Table 2 Descriptive Characteristics of Male Professional Cyclists Attending to Their Team Category

	WT (n = 98)	PT (n = 46)	*P*
Age, y	31 (6)	26 (4)	.003
Weight, kg	69.0 (7.3)	66.3 (6.0)	.083
Height, cm	181 (7)	179 (5)	.198
BMI, kg·m^{-2}	21.0 (1.4)	20.7 (1.2)	.289
Experience, y	9 (2)	4 (2)	<.001

Abbreviations: BMI, body mass index; PT, ProTeam; WT, WorldTour. Note: Data are shown as mean (SD).

particularly sprinters and all-rounders at longer durations (10, 120, and 180 min compared to time trialists [$d = 0.86$–1.04], and at all durations ≥5 min compared to sprinters [$d = 1.27$–2.69] and all-rounders [$d = 0.73$–1.24]). In turn, sprinters attained the highest relative MMP values for efforts lasting 5 to 30 seconds, presenting significant differences with all-rounders (1, 5, and 10 s, $d = 0.91$–1.36), time trialists (5, 10, and 30 s, $d = 1.57$–2.46), and climbers (1, 5, 10, and 30 s, $d = 1.21$–1.99). No significant differences in relative MMP values were found between sprinters and GC contenders for short-duration efforts (≤1 min), nor between time trialists and all-rounders for any effort duration.

When attending to absolute MMP values, GC contenders showed nonsignificant and small to moderate differences compared to time trialists, all-rounders, or climbers for all effort duration, except for a higher 1-second MMP when compared with the latter ($d = 1.34$), as per Figure 4. However, sprinters attained significantly higher absolute MMP values for short-duration efforts (≤1 min) than all other categories, including GC contenders ($d = 1.68$–3.98 for all), presenting higher absolute MMP values than climbers for all effort durations ($d = 1.55$–4.72). Climbers presented the lowest absolute MMP values, with significantly lower MMP values compared not only to sprinters, but also to all-rounders (from 1 s to 10 min, $d = 0.51$–1.08, with a trend toward lower MMP values also observed for 10, 120, 180, and 240 min [$P < .1$, $d > 0.45$]) and time trialists (with a significant or quasi-significant trend [$P < .1$] observed for all durations, $d = 0.85$–1.37). All-rounders also attained a lower absolute MMP for 60 minutes compared to time trialists ($d = 1.27$).

Discussion

The present study describes the RPP of a large cohort of professional cyclists, to the best of our knowledge the largest to date, and provides reference MMP values that can be used by coaches and sport scientists to compare the capabilities of the cyclists under their supervision with those of professional cyclists. Our findings also reveal some differences regarding the RPP of professional cyclists belonging to different categories and riding typologies. This supports the sensitivity of the RPP as a tool for assessing cyclists' capabilities.

Different studies have reported the RPP of professional cyclists during competition,[8] but limited data exist on the RPP of professional cyclists, including training data, which might result in higher MMP values. Pinot and Grape reported the RPP of 17 male cyclists (including professional and elite [first category in France, including cyclists of the category aged less than 23 y of age, U23]) with training and competition data obtained across an entire competition season. More recently, Van Erp et al[10] reported the RPP (although with few MMP values [10 s, 1 min, 5 min, and 20 min]) of 26 male professional cyclists from WT and PT teams during 7 seasons including both training and competition data. The present study suggests that, in order to be competitive (>75th percentile), cyclists must reach uniquely high MMP values (eg, >6.3, 5.5, 4.9, and 4.4 W·kg^{-1} for the 20, 60, 120, and 240 min MMP). On the other hand, the reference values presented here might be useful in classifying other athletes' capabilities. For instance, the values reported by Van Erp et al[10] for professional cyclists would fall around the 50th percentile of our normative values, whereas those reported by Pinot and Grappe[6] would fall between the 10th and 25th percentile. Interestingly, the MMP values presented here are also much higher than those obtained solely from single-day or multistage

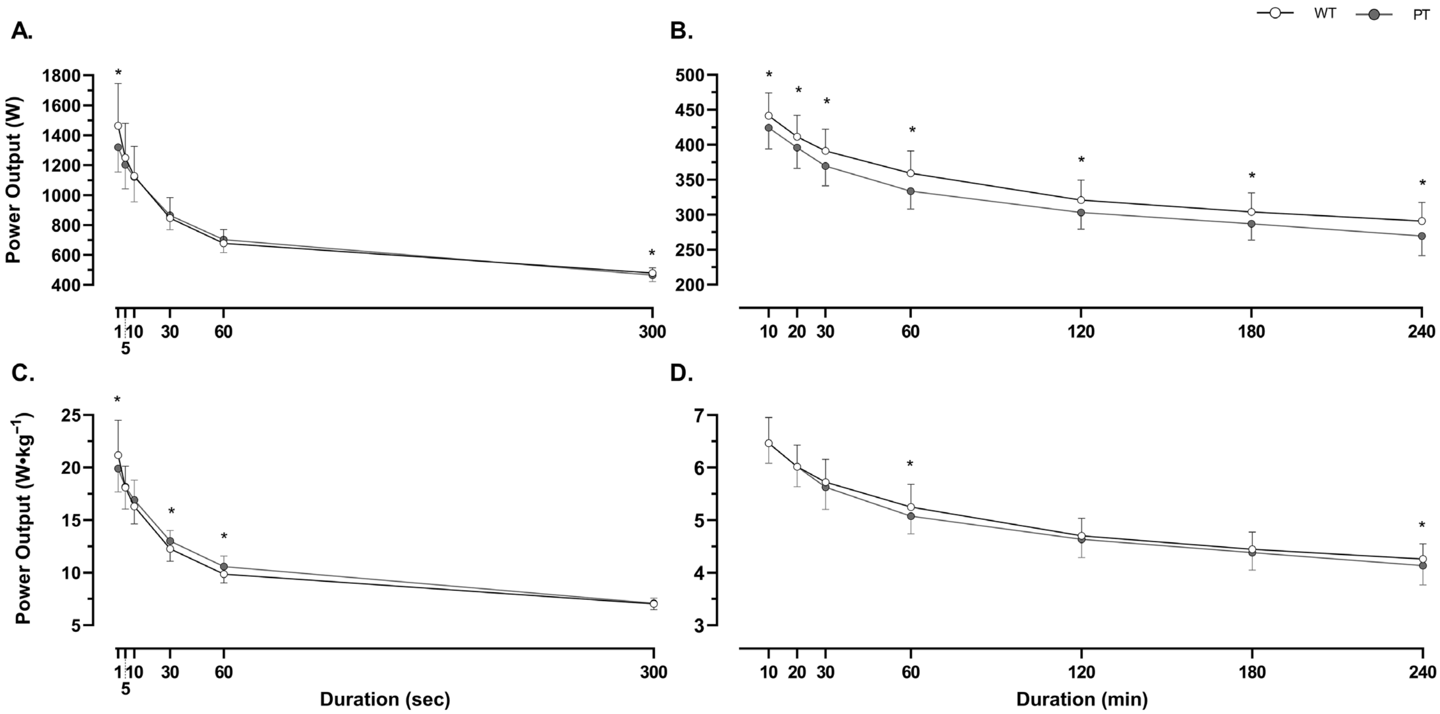

Figure 1 — Power profile of WT versus PT riders expressed as absolute power (A, B) or power relative to weight (C, D). *Significant difference between WT and PT. PT indicates ProTour; WT, WorldTour.

races,[8,23] which reinforces the importance of considering both training and competition data to accurately assess cyclists' capabilities. Finally, the present study suggests that a cyclist must be able to attain similar MMP values than those attained by the best specialists (eg, similar relative MMP values to climbers and similar absolute MMP values than time trialists) to be in position to win a Grand Tour. Contrastingly, climbers usually have high and low relative and absolute MMP values, respectively, whereas sprinters present the highest absolute MMP values for efforts lasting 5 to 30 seconds.

The present study also suggests that the RPP can enable differentiation between PT and WT cyclists. Some differences were also found in cyclists' typology with *climbers*, and particularly GC contenders, showing the highest relative MMP values for long durations, *time trialists* presenting the highest absolute MMP values for long durations (albeit not significantly different than those attained by GC contenders) and *sprinters* attaining the higher absolute MMP values for short durations. Some authors have reported that the power profile assessed under laboratory conditions seems sensitive enough to differentiate competitive from noncompetitive cyclists.[13] However, controversy exists regarding the sensitivity of power profiles assessed in field conditions, particularly when not computed from ad hoc tests, as in the case of the RPP. In line with our findings, Pinot and Grappe computed the RPP from data obtained during an entire competition season. Although they found no significant differences as to the cyclists' levels, professional riders tended to achieve higher PO values than elite cyclists for durations ranging from 5 minutes to 1 hour.[6] In turn, cyclists classified as *sprinters* achieved higher PO values at short durations (1–5 s) than *flat specialists* and *climbers*, whereas the latter achieved higher PO values in efforts of a longer duration (5–240 min).[6] Also, supporting the sensitivity of the RPP, we recently assessed the RPP of professional cyclists belonging to 2 different categories (WT and PT) during a Grand Tour. It was noted that, even though cyclists attained similar MMP values during the whole race (thus attending to the highest values attained during the 3 wk) regardless of their categories, WT cyclists showed higher MMP values as the race progressed, that is, during the second and third weeks.[24] Van Erp and Sanders[23] reported that MMP values (particularly for short duration, ie, <5 min) obtained during racing were a differentiating factor between top-10 professional cyclists and those with a lower performance level. Leo et al[25] reported that changes in absolute MMP values (2, 5, and 12 min) during a season in U23 professional cyclists correlated to the changes observed in training loads, which might also support the sensitivity of the RPP.

Although the aforementioned findings would support the sensitivity of the RPP, Leo et al[14] reported no changes in absolute MMP values during a season in U23 professional cyclists, with the changes observed in relative MMP values attributable to changes in body mass. In addition, some authors have reported that the MMP values registered during competition are similar to the power profiles registered in laboratory conditions,[26] yet Leo et al[14] found that MMP values during preseason training sessions were lower than those obtained during field-based tests. Similarly, Leo et al[14] also reported that MMP values were lower in training sessions than in competitions.[25] Thus, some concerns remain regarding the sensitivity of the RPP for monitoring changes in performance, at least when assessed in absolute units, and *particularly* when obtained solely from training sessions. On the other hand, even if no differences in MMP values had been noted between team categories, several other factors could affect cycling performance.[9] Although we observed no differences in MMP values between WT and PT cyclists during an entire race in previous studies, differences appeared during the last weeks.[24] Van Erp et al[10] and Leo et al[27] also recently reported that no overall differences in MMP

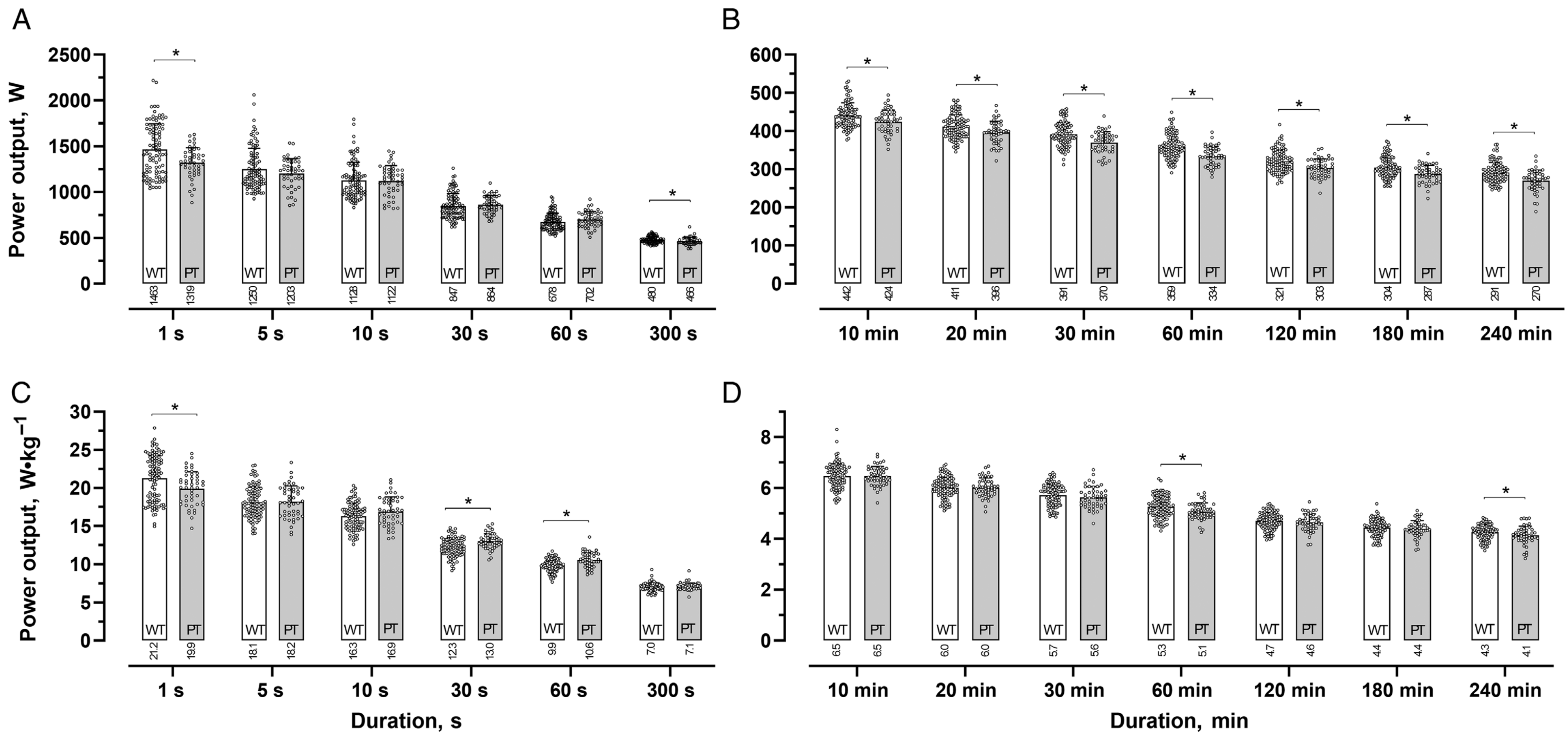

Figure 2 — Individual and mean maximal power values attained at the different power profile time points, expressed as absolute power (A, B) or power relative to weight (C, D), in WT and PT riders. PT indicates ProTour; WT, WorldTour. *Significant differences between categories.

Table 3 Descriptive Characteristics of Male Professional Cyclists Attending to Their Riding Typology

	All-rounders (n = 65; WT = 36 and PT = 29)	Time-trial specialists (n = 11; WT = 9 and PT = 2)	Climbers (n = 50; WT = 34 and PT = 16)	GC contenders (n = 7; WT = 7 and PT = 0)	Sprinters (n = 11; WT = 11 and PT = 0)
Age, y	29 (6)	33 (6)	30 (6)	32 (6)	28 (3)
Weight, kg	69.5 (5.5)[c,e]	72.6 (5.4)[c,d,e]	63.2 (4.4)[a,e]	63.8 (4.5)[b,e]	80.2 (6.5)[a–d]
Height, cm	181 (6)[c]	184 (8)[c]	177 (6)[a,e]	176 (7)[e]	187 (6)[c,d]
BMI, $kg \cdot m^{-2}$	21.1 (1.3)[c,e]	21.4 (0.9)[c,e]	20.2 (1.1)[a,e]	20.5 (0.8)[e]	23.0 (1.5)[a–d]
Experience, y	7 (5)	9 (5)	7 (5)	9 (5)	6 (3)

Abbreviations: BMI, body mass index; GC, general classification; PT, ProTeam; WT, WorldTour. Note: Data are shown as mean (SD).
Significant differences: [a]significantly different than all-rounder; [b]significantly different than time trialist; [c]significantly different than climber; [d]significantly different than GC contenders; [e]significantly different than sprinters.

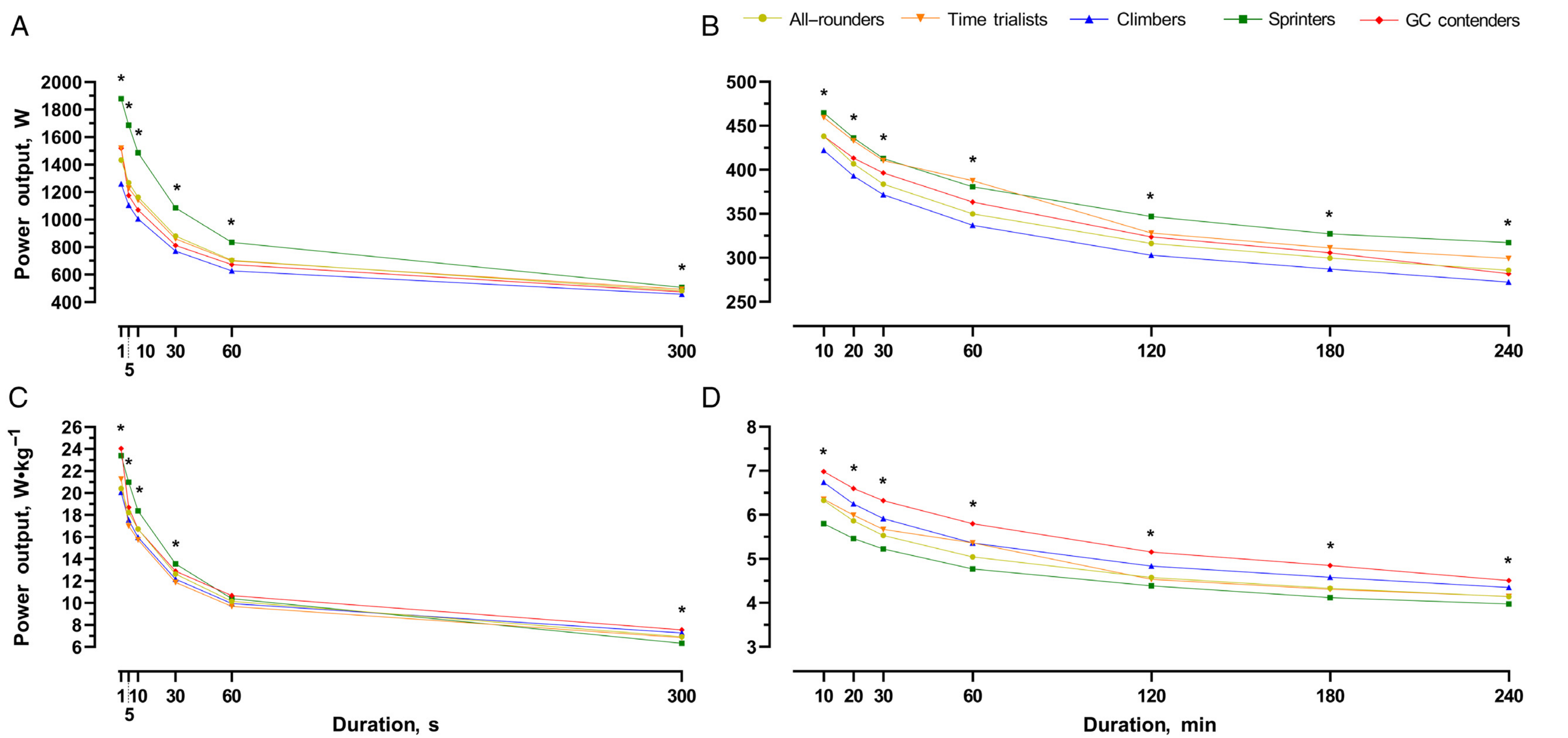

Figure 3 — Power profile of all-rounders, time trial specialist, climbers, sprinters, and GC contenders expressed as absolute power (A, B) or power relative to weight (C, D). *Significant differences between the different riding typologies; see Figure 4 for details. GC indicates general classification.

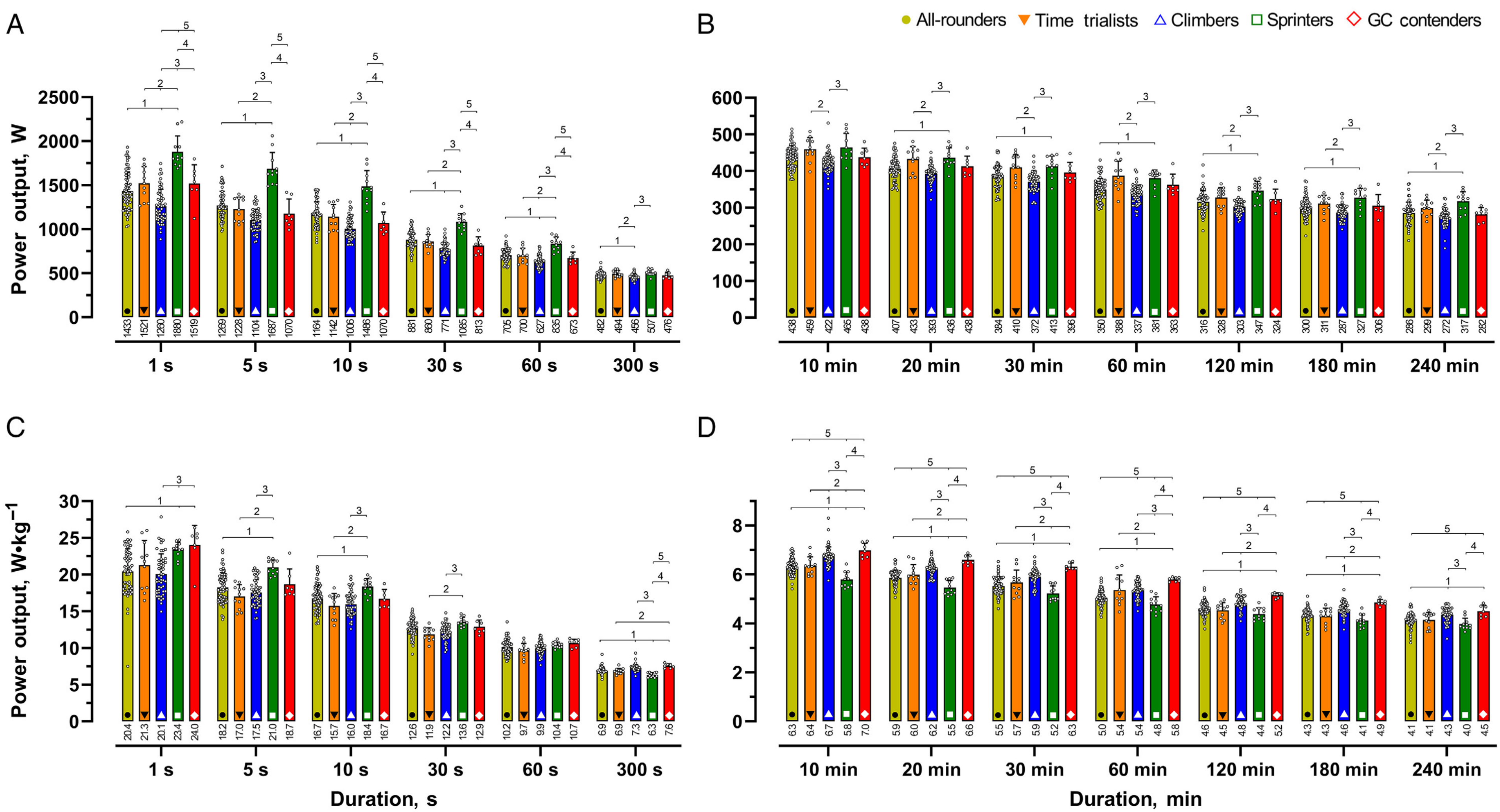

Figure 4 — Individual and mean maximal power values attained at the different power profile time points, expressed as absolute power (A, B) or power relative to weight (C, D), in all-rounders, time trialists, climbers, sprinters and GC contenders. 1: different from all-rounders, 2: different from time trialists, 3: different from climbers, 4: different from sprinters, and 5: different from GC contenders. GC indicates general classification.

values between professional cyclists of different categories, or team roles, when obtained under rested conditions were noted. However, differences emerged along with accumulating levels of fatigue. These findings would imply that factors, such as the ability to recover between efforts, might be more important than the ability to produce high MMP values on a single occasion. Variables such as team tactics, drafting, and/or environmental conditions can also influence MMP values and actual cycling performance,[9] and therefore MMP values should not be considered the sole determinant of performance.

In addition to analyzing the sensitivity of the RPP, the present study provides normative MMP values for a wide range of durations. Previous studies have proposed some reference values for laboratory-based physiological measures that would characterize professional cyclists.[1,11,12] For instance, Jeukendrup et al[1] reported the economy, VO_2max, and peak power output of a small group of World Class cyclists, albeit no information regarding the subjects was provided. Based on a systematic review, de Pauw et al[11] proposed a range of VO_2max and peak power output values that could characterize professional cyclists. Other studies have reported the power profile obtained under laboratory conditions in junior triathletes,[28] or mountain bikers,[13] while others have reported the RPP in professional cyclists obtained during races,[8] or in U23 professional cyclists during different periods of a season (including the MMP for 3, 5, and 12 min).[14,25] However, to our knowledge, this present study is the first to report reference values for the RPP, computed with the highest MMP data yielded by a large group of professional cyclists, analyzing different seasons and including both races and training sessions. Based on the depth of the data, this study is thus more likely to represent cyclists' actual capabilities. We also report the RPP of 7 cyclists who competed for a top-5 position during grand tours (here considered as GC contenders), which probably represent the highest level of cycling performance.

Some limitations of the present study should be acknowledged. We found some unexpected differences in the RPP between WT and PT cyclists with the former attaining higher MMP values at longer durations, but lower values at shorter durations (30–60 s). Further research is needed to confirm our findings. As highlighted by other authors,[14] an inherent issue with the determination of the RPP is that MMP values might not necessarily correspond to the highest PO attainable by the cyclist. In this regard, the MMP values presented here for very short-duration efforts (eg, 1–30 s) might be lower compared with a laboratory-based test. In the same line, the MMP values that we recorded for longer efforts (eg, 240 min), which are likely to include intermittent efforts of varying intensities, might also be lower than those potentially attainable during a laboratory steady-state test. In addition, we joined competition and training data in our analyses despite preliminary evidence suggesting that MMP values differ between racing and training[25] and more research is needed to determine how each riders' typology affects performance in each type of stage. Finally, the use of 5 different power meters could have potentially confounded our results, although the power meters used here have been previously used in the scientific literature and are widely used among professional cyclists.[16–19]

Practical Applications

The results presented in this study might support the role of a field-based performance indicator, such as the RPP, as a tool to monitor cyclists' capabilities. Moreover, coaches and sport scientists could use the normative values (based on the largest group of professional cyclists assessed to date and including cyclists from different teams, different team roles and categories, as well as some GC contenders who represent the highest level of cycling performance) as a reference to compare the capabilities of cyclists under their supervision with those of professional cyclists.

Conclusions

Our findings suggest that the RPP, particularly when expressed in relative units, enables differentiation of cyclists based on team categories (WT vs PT) or riding typologies (eg, climbers vs time trialists). This might support the sensitivity of the RPP as a tool to monitor cyclists' capabilities.

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