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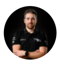

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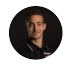

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Human Kinetics
BRIEF REVIEW

# The Physical Demands and Power Profile of Professional Men's Cycling Races: An Updated Review

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***Background:*** A variety of intensity, load, and performance measures (eg, "power profile") have been used to characterize the demands of professional cycling races with differing stage types. An increased understanding of the characteristics of these races could provide valuable insight for practitioners toward the design of training strategies to optimally prepare for these demands. However, current reviews within this area are outdated and do not include a recent influx of new articles describing the demands of professional cycling races. ***Purpose:*** To provide an updated overview of the intensity and load demands and power profile of professional cycling races. Typically adopted measures are introduced and their results summarized. ***Conclusion:*** There is a clear trend in the research that stage type significantly influences the intensity, load, and power profile of races with more elevation gain typically resulting in a higher intensity and load and longer-duration power outputs (ie, >10 min). Flat and semimountainous stages are characterized by higher maximal mean power outputs over shorter durations (ie, <2 min). Furthermore, single-day races tend to have a higher (daily) intensity and load compared with stages within multiday races. Nevertheless, while the presented mean (grouped) data provide some indications on the demands of these races and differences between varying competition elements, a limited amount of research is available describing the "race-winning efforts" in these races, and this is proposed as an important area for future research. Finally, practitioners should consider the limitations of each metric individually, and a multivariable approach to analyzing races is advocated.

***Keywords:*** elite, power output, heart rate

Cycling, as a sport, includes a variety of different types of bicycles and environmental settings for several different cycling specialties. These include mountain biking, track cycling, BMX, and cyclo-cross, although by far the best-known competitive cycling specialty is road cycling. Competitive road cycling is a sport practiced worldwide with the Tour de France being one of the world's biggest sporting events. There are road cycling competitions all around the world across a broad spectrum that ranges from youth and junior to elite professional competitions.

A professional cyclist active in the highest division, the World Tour, will cycle up to 35,000 km in training and competition each year.[1] This can include up to 90 competition days with a high probability of participating in at least one, if not more, of the 3 Grand Tours (Giro d'Italia, Tour de France, and Vuelta a España). Competition days in cycling include both single-day and multiday (stage) races. Multiday races are often differentiated between different stage types: flat stages, time trials (TTs), semimountainous stages, and mountain stages.[2–7] Most professional cyclists are specialized in 1 or 2 of these stage types, and physiological and anthropometric measures can greatly differ depending on each specialty (Table 1).[1,8,9] In addition to stage races, there is also a wide array of single-day races which greatly vary in profile/elevation gain and route. These include, among others, the single-day races called the "Monuments" (ie, Milan–San Remo, Tour of Flanders, Paris–Roubaix, Liege–Bastogne–Liege, and Giro di Lombardia), which are considered to be the oldest, hardest, and most prestigious 1-day events in professional cycling. Furthermore, within professional cycling, races recognized by the Union Cycliste Internationale are classified into different categories such as World Tour Cycling, Hors Catégorie, level 1, and level 2 races.

Due to technological advancements over the years with the introduction of mobile heart rate (HR) and power meters, the collection of both physiological (ie, HR) and "work rate" (ie, power output) data in the field, it is now widely possible to monitor the training and competition of professional cyclists. As a result of this accessible data collection, both applied and more descriptive studies on professional cyclists have been presented in recent decades.[8,10–16] In these studies, the intensity, load, and performance measures (eg, power profile; maximal mean power output data over different durations) during competitions have been described to characterize the demands of professional cycling races with varying competition elements,[2,6,7,17] to compare Grand Tours,[18] to compare single-day versus multiday races,[15,19] and to compare professional cycling races of the different categories.[20] Given the variety of stage types and competition elements in professional cycling, having a way to characterize each of these stage types is essential in getting an understanding of the race demands. Obtaining an accurate understanding of the intensity, load, and power profile demands of cycling races would allow the design of training strategies to optimally prepare for these demands, so its integration with race (performance) analyses should be deemed important. To date, there are several reviews available that describe the physiological characteristics of professional cyclists,[1] the analysis and utilization of cycling training data,[21] factors influencing cycling performance,[22,23] or the physiological characteristics of cyclists competing in the Tour de France.[24] However, these reviews are outdated (ie, the last review specifically focusing on professional cyclists was in 2005) and thus do not include a recent influx of new articles describing the physical demands and power profiles of professional cycling races.[2–5,15,17,20,25–27]

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**Table 1 General Characteristics of Different Stage Types Typically Present Within a Grand Tour (ie, FLAT, SMT, MT, and TT) and Non-Grand-Tour Stages (ie, Single-Day and Multiday Races)**

| | Grand Tour[a] | | | | Non-Grand-Tour[a] | |
|---|---|---|---|---|---|---|
| | FLAT | SMT | MT | TT | Single-day | Multiday |
| Days | 5–8 | 4–6 | 6–9 | 1–3 | 1 | 2–10 |
| Distance, km | ~150 to 220 | ~150 to 220 | ~150 to 200 | <60 | ~200 to 250 (max 300) | ~150 to 240[c] |
| Time, h | ~4 to 5 | ~5 to 6 | ~5 to 6 | <1 | ~5 to 6 (max 7.5) | ~4 to 5 |
| Mean speed, $km{\cdot}h^{-1}$ | ~45 | ~40 | ~35 (uphill <30) | ~50 | ~40 | ~35 to 40 |
| TEG, m | <2000[b] | >2000[b] | >3000[b] | <1000 | ~1000 to 2500 (max 4500) | ~2200 to 2500 (average) |
| Typical decisive specialty | Sprinters or “flat specialists” | Punchers or climbers | Climbers | TT and GC specialists | Varied depending on race profile | Varied depending on race profile |
| Key performance indicators | High absolute 1- to 30-s PO | High absolute and relative 30-s to 10-min PO | High relative 20- to 60-min PO | High 10- to 60-min absolute PO relative to aerodynamics | Varied depending on race profile | Varied depending on race profile |

Abbreviations: FLAT, flat stages; GC, general classification; MT, mountain stages; PO, power output; SMT, semimountainous stages; TEG, total elevation gain; TT, time trial.
[a] Results presented as averages across a whole range of the races. Numbers outside of these ranges will be observed in each of the (single) stages within the multiday race or a specific single-day race. [b] Besides the total elevation gain, the place of uphill sections (eg, beginning, middle, end) also influences the stage-type classification (eg, flat stage has no uphill sections at the end; stage can still be classified as a mountain stage with total elevation gain being less than 3000 m, but the stage finishes with a climb of at least 10 km. See, eg, Padilla et al[6]). [c] The maximal allowed mean daily distance for a multiday race is 180 km.

In addition, previous reviews focused largely on HR data with limited data describing the power output characteristics of professional cycling races. Therefore, this review aims to provide an updated overview of the intensity and load demands and power profile of professional cycling races. In the following sections, metrics (intensity, load, and power profile) typically used to characterize professional cycling races are firstly introduced, and the evidence base regarding the utilization of these measures in the description of races is subsequently described.

## Intensity

While there are numerous physiological variables available to measure exercise intensity in more lab-based settings (eg, oxygen consumption), practically measuring the intensity of professional cycling races basically comes down to three variables: rating of perceived exertion (RPE), HR, and power output.[2,15,16] HR and power output can be measured continuously throughout the race and are analyzed retrospectively while RPE is typically collected post-race. In addition to solely looking at “mean intensity measures” (eg, “This race was on average 220 W with a mean HR of 148 bpm and the rider’s RPE was a 7”), analyzing accumulated time spent in different intensity zones is another commonly adopted approach to characterize the demands of cycling races.[2,14,15] Typically adopted within such research is the use of a 3-zone intensity model,[28–30] where physiological thresholds based on blood lactate concentrations or the first and second ventilatory thresholds have been used as physiological markers to define the intensity zones.[28,29] Zones are defined as “low intensity” (zone 1, $<VT_1/LT_1$), “moderate intensity” (zone 2, between $VT_1/LT_1$ and $VT_2/LT_2$), and “high intensity” (zone 3, $>VT_2/LT_2$). While the determination of such zones around a metabolic threshold/inflection point is advocated,[28,29] when data on such thresholds are not available or data are analyzed retrospectively, studies have also used a 5-zone model based on a percentage of maximal HR to quantify intensity distribution[15,16] or have adopted a 5-zone model with power output zones anchored around the functional threshold power (Figure 1).[16,27]

Overall, intensity of professional cycling races seems to vary, on average, between 2.70 and 3.50 $W{\cdot}kg^{-1}$ based on the current body of research with numbers outside of this range also being reported. Most research that looked at HR measures during professional (mass-start) cycling races showed that mean HR as a percentage of maximal HR ($\%HR_{max}$) varies between 66% and 76% with higher numbers being reported in individual and team TTs.[7] Only Padilla et al,[6] who looked at different stage types in a cycling Grand Tour, showed $\%HR_{max}$ numbers that are substantially lower compared with other published research ($\%HR_{max}$ varying between 51% and 61%). In terms of subjective responses (ie, RPE), it seems that most cyclists rate a professional cycling race, on average, between 5.0 and 8.0 on the Borg CR-10 scale[2] or between 14.5 and 16.0 on a Borg 6 to 20 scale[15,20], which would be considered to be between “somewhat hard” (ie, a score of 4.0 and 13.0, respectively) and “very hard” (ie, a score of 7.0 and 17.0, respectively). Nevertheless, important to consider with all these reported results is that they only represent a mean for the whole stage, these ranges must be considered relatively wide, and there are substantial between-stage and between-research differences observed. Factors contributing to differences in the intensity of a cycling race are varied and can include, among others, race tactics or strategy, course profile (eg, elevation gain), and race length (ie, single-day vs multiday races).

It is clear from the current published research that stage type of mass-start stages (eg, flat stage vs [semi]mountain stage) substantially influences the intensity of the race/stage. A general trend can be seen: the higher the elevation gain of the stage, the higher the observed intensity, regardless of the measure used. For example, Sanders and Heijboer[2] analyzed a variety of stage types (ie, flat, semimountainous, and mountain stages) within a Grand Tour and

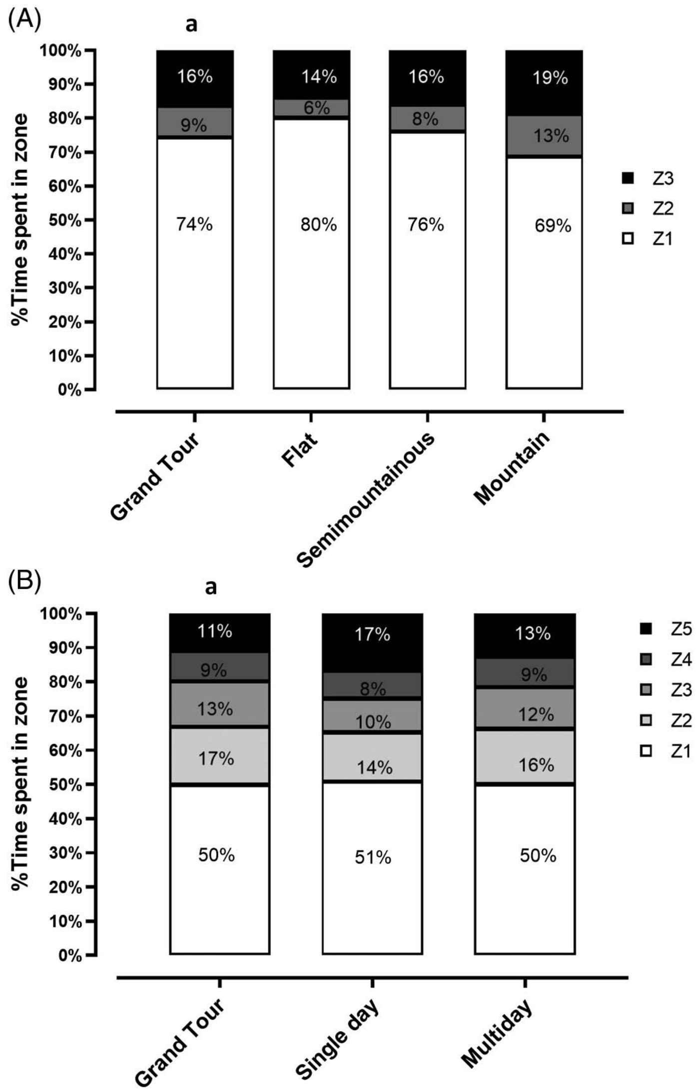


**Figure 1** — (A) Intensity distribution as percentage of time spent in different power output zones in overall Grand Tour stages and for the different race types (ie, flat, semimountainous, and mountain stages) for a 3-zone model.[2] (B) Intensity distribution as percentage of time spent in different power output zones in overall Grand Tour stages, single-day races, and multiday races based on a 5-zone model.[15] [a] Reanalyzed data from previously published research from our research group.[2,15]

reported that mountain stages have the highest intensity with mean power output of the whole stage being 3.50 W·kg$^{-1}$ (254 W) compared with 2.68 W·kg$^{-1}$ (217 W) and 2.99 W·kg$^{-1}$ (196 W) for flat and semimountainous stages, respectively. Furthermore, %HR$_{max}$ and RPE was highest in mountain stages (76% and 7.8 AU) compared with semimountainous (67% and 6.5 AU) and flat stages (67% and 5.8 AU). Similar results were observed in terms of intensity distribution with higher proportions of time being spent in moderate- (ie, zone 2) and high-intensity zones (ie, zone 3) in mountain stages compared with flat and semimountainous stages (Figure 1). Furthermore, when looking at load measures expressed per kilometer (eg, Training Stress Score [TSS]·km$^{-1}$), which arguably could be seen as an intensity measure, similar trends can be seen with mountain stages showing higher load per kilometer compared with semimountainous and flat stages. While Table 2 solely focuses on the demands of mass-start stages, it is clear from research that TTs present with the highest intensity due to their substantially shorter overall duration. For example, Padilla et al[7] analyzed the intensity of different TTs with varying durations and showed that the mean intensity varied between 80% HR$_{max}$ for longer TTs (ie, >40-km TT) up to 85% HR$_{max}$ for short TTs (ie, <40 km) and 89% HR$_{max}$ for prologues (ie, short opening TTs, <10 km). Furthermore, Sanders and Heijboer[2] showed that intensity was substantially higher during TTs compared with other stage types within a Grand Tour.

While research into this area is limited, the general trend from the research points toward a higher intensity of single-day races compared with multiday races. For example, Sanders et al[15] analyzed a large database of professional cycling races and reported higher power output (3.17 vs 2.99 W·kg$^{-1}$), higher %HR$_{max}$ (74% vs 69%), and higher RPE (16.1 vs 15.6 AU on the Borg 6–20 scale) for single-day races compared with multiday races. This is also shown in the intensity distribution with single-day races showing a higher proportion of time being spent in higher intensity zones (ie, zone 5 in a 5-zone model) compared with multiday races (Figure 1).[15] Explanations for this are relatively straight forward. Success in multiday stage races requires a stable and high-performance level spread out over multiple days while this is obviously not the case for a single-day race. Hence, cyclists will adopt more aggressive racing strategies during single-day races resulting in a higher intensity. Nevertheless, with these reported numbers, it is again important to acknowledge the large between-race differences that occur, even when comparing single-day races with each other. For example, while the research on this is very limited, recent observations from our research group show that race category will also influence the intensity of races.[20] In this study, it was shown that the intensity (measured with mean HR as %HR$_{max}$) of "Monuments" was higher compared with other World Tour races (75.0% vs 71.5%) despite these races having a substantially higher distance and duration.[20] Furthermore, there is also an accumulating body of evidence showing that overall race length (ie, amount of days) within multiday races influences intensity responses. Authors such as Rodríguez-Marroyo et al[26] and Sanders et al[14] showed that there are typical trends observed across the course of a 3-week Grand Tour: RPE increases week-to-week while there is a suppression of maximal and mean HR over the course of the Grand Tour. The accumulation of fatigue over the course of a Grand Tour most likely contributes to these results. Decreases in HR can be caused by a decreased sensitivity to catecholamines[33] and an exhaustion of the adrenal and testes glands, which has previously been shown to become evident at the end of Grand Tours.[34] Furthermore, the accumulation of fatigue contributes to higher RPE responses for the same external intensity (ie, power output).[14] These observed differences in intensity responses further advocate the use of monitoring intensity using a multivariate approach as it can provide valuable indications on the fatigue and fitness responses without the need to use any invasive measures or testing procedures.

## Competition Load

While the intensity of the race plays a large role in quantifying the demands of cycling races, the nature of cycling races (ie, lasting up to 7.5 h) makes the duration also an obvious important parameter in determining the overall stress or strain of a cycling race. Hence, measuring only intensity (eg, mean HR or power output) does not reflect the entire (physiological) demand. Load measures, which integrate both intensity and duration into one score, may therefore

**Table 2 Reported Mean Intensity and Load Characteristics in the Literature for Grand Tour (ie, Average Stage Without Differentiating for Stage Type, FLAT, SMT, MT) and Non-Grand-Tour Stages (ie, Single-Day and Multiday Races)**

| | Grand Tour | | | | Non-Grand-Tour | |
|---|---|---|---|---|---|---|
| **Measure** | **All** | **FLAT** | **SMT** | **MT** | **Single-day** | **Multiday** |
| PO, W | 229 (45)[14,a]<br>212 (35)[20] | 218 (21)[3]<br>196 (29)[2] | 228 (22)[3]<br>217 (20)[2] | 234 (13)[3]<br>254 (19)[2] | 225 (30)[15] | 213 (32)[15] |
| PO, $W \cdot kg^{-1}$ | 3.13 (0.61)[14,a]<br>2.89 (0.44)[20] | 3.10 (0.30)[3]<br>2.68 (0.32)[2] | 3.30 (0.30)[3]<br>2.99 (0.27)[2] | 3.30 (0.20)[3]<br>3.50 (0.31)[2] | 3.17 (0.41)[15] | 2.99 (0.43)[15] |
| Mean HR, bpm | 129 (6)[14,a]<br>141 (1)[26]<br>125 (12)[20]<br>134 (18)[31] | 133 (10)[3]<br>125 (9)[2]<br>127 (10)[31]<br>126 (14)[31]<br>119 (10)[6] | 134 (8)[3]<br>128 (4)[2]<br>130 (9)[6] | 140 (3)[3]<br>141 (10)[2]<br>130 (8)[31]<br>135 (10)[31]<br>135 (9)[6] | 140 (10)[15] | 148 (3)[26]<br>146 (1)[26]<br>130 (10)[15] |
| Peak HR, bpm | 178 (9)[14,a]<br>172 (21)[20] | 177 (10)[2] | 173 (4)[2] | 177 (11)[2] | ND | ND |
| $\%HR_{max}$ | 66 (6)[14,a]<br>66 (6)[20] | 67 (5)[2]<br>51 (7)[6] | 67 (2)[2]<br>58 (6)[6] | 76 (5)[2]<br>61 (5)[6] | 74 (5)[15] | 69 (5)[15] |
| RPE | 6.7 (1.9)[14,a]<br>5.9 (0.1)[26]<br>14.5 (2.6)[20] | 5.8 (1.9)[2] | 6.5 (1.3)[2] | 7.8 (1.5)[2] | 16.1 (1.9)[15,b] | 5.0 (0.3)[26]<br>5.1 (0.2)[26]<br>15.6 (2.0)[15,b] |
| sRPE | 1939 (873)[14,a] | 1657 (546)[2,a] | 2030 (481)[2,a] | 2481 (753)[2,a] | 4655 (2427)[15,b] | 4282 (2137)[15,b] |
| TSS | 264 (98)[14]<br>254 (63)[20] | 217 (46)[2] | 280 (40)[2] | 329 (83)[2] | 286 (80)[15] | 254 (63)[15] |
| bTRIMP | 340 (128)[14,a] | 156 (31)[6] | 172 (31)[6] | 215 (38)[6] | ND | ND |
| eTRIMP | 624 (231)[14,a]<br>688 (203)[20] | 549 (153)[2,a] | 599 (161)[2,a] | 860 (245)[2,a] | 868 (207)[15] | 702 (186)[15] |
| luTRIMP | 340 (84)[14,a]<br>316[32,c]<br>299[32,c] | 298 (33)[2] | 311 (53)[2] | 359 (80)[2] | ND | 401[25,c]<br>392[25,c] |
| iTRIMP | 310 (148)[14,a] | ND | ND | ND | ND | ND |
| kJ spent | 3851 (951)[20] | ND | ND | ND | 3964 (962)[15] | 3673 (895)[15] |
| $TSS \cdot km^{-1}$ | 1.38 (0.34)[20] | 1.14 (0.19)[2] | 1.32 (0.20)[2] | 1.97 (0.31)[2] | 1.49 (0.27)[15] | 1.41 (0.30)[15] |
| $eTRIMP \cdot km^{-1}$ | 3.37 (1.09)[20] | ND | ND | ND | 4.63 (0.72)[15] | 4.04 (0.90)[15] |
| $luTRIMP \cdot km^{-1}$ | 2.48[25,c] | 1.55 (0.13)[2] | 1.52 (0.14)[2] | 2.10 (0.15)[2] | ND | 3.09[25,c]<br>2.71[25,c] |
| $kJ \cdot km^{-1}$ | 20.9 (4.86)[20] | ND | ND | ND | 20.45 (6.03)[15] | 20.44 (6.30)[15] |

Abbreviations: All, stages on average without differentiating for stage type; bpm, beats per minute; bTRIMP, Banister's TRIMP; eTRIMP, Edwards' TRIMP; FLAT, flat stages; HR, heart rate; $HR_{max}$, maximal heart rate; iTRIMP, individualized TRIMP; luTRIMP, Lucia's TRIMP; MT, mountain stages; ND, no data available in the literature; PO, power output; RPE, rating of perceived exertion; SMT, semimountainous stages; sRPE, session RPE; TRIMP, training impulse; TSS, Training Stress Score. Note: Values are presented as mean (SD).

[a] Reanalyzed data from previously published research from our research group. [b] Borg 6–20 scale. [c] Not directly reported but estimated/calculated based on data in the article; hence no SD.

be a better reflection of the resulting physical "stress" of a cycling race compared with measures of duration or intensity alone.[6,7,17] A distinction can be made between external and internal training load depending if we are referring to measurable aspects occurring internal or external to the athlete (we refer the readers to these articles[35,36] which describe these concepts in greater detail).

Load measures typically used in research to describe the demands of professional cycling races include the HR-based training impulse (TRIMP) metrics, the power output-based TSS,[37] and the subjective-based session RPE (sRPE).[38] While important differences exist between each measure, they have one commonality: providing an overall score indicating the overall "physical stress" of that training or race by integrating intensity and duration. After the introduction of the original Banister's TRIMP,[39] multiple other variations of TRIMP are developed and used to describe the load demands in professional cycling. Potentially due to their simplicity, highly used are Edwards' TRIMP (eTRIMP)[40] and Lucia's TRIMP (luTRIMP),[18] which are based on a 5-zone and a 3-zone concept, respectively. The duration spent in each zone is multiplied by a weighting factor from 1 to 5 or 1 to 3 and then summated to provide a total eTRIMP or luTRIMP score. Furthermore, an individualized TRIMP[41] method is developed, where the individual's HR–blood lactate relationship is used to calculate the exponential factor for weighting exercise intensity. Arguably the most easy to collect and calculate load metric is the abovementioned (subjective) load measure sRPE, which is calculated by simply multiplying the postexercise RPE with the training duration.[38] After the introduction of the power meter, TSS was developed, which is a power output-based load metric integrating a "smoothed" mean power (ie, normalized power) and the cyclist's functional threshold power.[37] Noteworthy, although a variety of load measures are used to describe the load demands in professional races, there is limited evidence about the validity of those measures (and related concepts, eg, "normalized power") and it is obvious that differences between load metrics will exist due to differences in calculations. For example, van Erp et al[42] showed that TSS reacts differently to exercise intensity compared with luTRIMP and sRPE. Sanders et al[43] found that load measures which integrate individual physiological characteristics (ie, TSS and individualized TRIMP) have the strongest dose–response relationship in amateur well-trained cyclists. However, this is the only study evaluating the relationship between commonly used training load measure and their relationship with changes in fitness in trained cyclists. Furthermore, this study was conducted in the general preparation phase, questioning if these relationships would be maintained in specific (higher intensity) training or competition phases or with professional cyclists.

Various load measures during competitions have been used to characterize the demands of professional cycling races with varying competition elements,[2–4,6,17,31] Grand Tours,[3,4,14,18,27,44,45] single-day versus multiday races,[15,25] and different race categories[20] (Table 2). Similar to the results for the intensity measures, the reported ranges for each load measure must be considered wide and are influenced by a variety of factors similar to the ones mentioned previously (ie, race tactics or strategy), course profile (eg, elevation gain), and race length (ie, single-day vs multiday races). For example, mean TSS and eTRIMP scores have been reported to range between 217 and 329 AU and 548 and 868 AU, respectively, depending on the type of race analyzed. Furthermore, often these numbers are mean values reported in studies evaluating a larger number of races; hence, values outside of these ranges will also be observed in practice. For example, a recent study showed that the longest 1-day races (ie, Monuments) can have TSS and eTRIMP scores of >400 and >1280 AU, respectively.

Multiple studies have highlighted the differences between the load demands of different race types (ie, flat, semimountainous, and mountain stages) within a Grand Tour.[2–4] Expectedly similar to the intensity demands, it is clear from the published research[2,3,6] that stage type also influences the load demands. Mountain stages typically have a higher intensity and duration and thus typically also are presented with a higher load. For example, Sanders and Heijboer[2] presented a substantial higher load measured with TSS and sRPE during mountain stages (329 and 2416 AU, respectively) compared with flat (217 and 1578 AU, respectively) and semimountainous stages (311 and 2022 AU, respectively).[2] While TTs have a substantially higher exercise intensity compared with mass-start stages, as mentioned in the previous section, the lower duration of TTs still results in TTs' having a lower load compared with mass-start stages. This suggests that the higher intensity does not compensate for the substantially lower duration in terms of overall race load. For example, Sanders and Heijboer[2] evaluated the load of TTs in a Grand Tour with numbers of 62 and 33 AU for TSS and luTRIMP being reported, respectively, which is substantially lower compared with the load for mass-start stages (Table 2). However, the load demands of a TT obviously highly depends on the duration/distance of the TT.[7]

Similar to intensity, it also seems that the number of stages within a race influences the load demands of a race.[15,25] This can be largely attributed to differences in race regulations. For example, a category 1 or "Hors Catégorie" stage within a multiday race is limited to a maximum mean daily distance of 180 km in contrast to a single-day race of the same categories which are limited to 200 km. Furthermore, there is no limit for single-day races at World Tour level (Table 1). The longer duration in combination with the mentioned higher intensities for the single-day races will result in a higher load. This is clearly visible in Table 2, which presents the differences between multiday and single-day races for the various load measures. On average, single-day races are roughly ~10% (ie, TSS and sRPE) to ~25% (ie, eTRIMP) higher in terms of load compared with a stage within a multiday race.[15] The difference between an HR-based (~25%) and a power output-based load measure (~10%) could partly be explained by the suppression of maximal and mean HR due to accumulated fatigue mentioned in "Intensity" section.[18,45] A power output-based load measure is potentially less affected by fatigue and thus differences between single-day and multiday races will be smaller for a measure such as TSS in contrast to an HR-based load measure like any of the TRIMP measures reported in Table 2.

## Power Profile

While the use of power output as intensity and load measures has been described previously, a separate methodology to evaluate the demands of professional cycling races is monitoring the absolute and relative maximal mean power outputs over different durations. Such methodologies have been termed the power profile[46] or "record power outputs."[8] Studies which describe the power profile have used a variety of durations and number of durations. The durations are somewhat arbitrarily chosen but mostly used in the literature are combinations of the following durations: 1, 5, 10, 15, 20, and 30 seconds and 1, 2, 3, 5, 10, 20, 30, 60, 120, and 180 minutes and are together with the number of durations (ie, from 9 up to 13)[2–4,20,27] chosen to capture the whole array of power outputs needed to characterize professional cycling (races). Furthermore, not only demands of professional cycling races are described with the power profile, but it is also common practice to evaluate the power profile for an individual cyclist, that is, the maximum mean power output that an individual rider can produce over different durations. This has been proven useful in characterizing different rider types (ie, sprinter, climber, TT specialist) and identifying strengths and weaknesses of individual riders.[8] Therefore, evaluating maximal mean power outputs over a variety of durations to characterize races and individuals is a highly used tool within professional cycling and potentially one of the most valued methods considering its more direct link with actual race performance/results in contrast to intensity and load measures.

Multiple studies used the power profile to describe the demands of professional cycling races, which are summarized in Figure 2 (excluding case reports).[2–4,20,27,47] As mentioned earlier, road races can be categorized into different race types (ie, flat, semimountainous, and mountain stages), which each have their own specific power profile "fingerprint." In general, flat and semimountainous stages are characterized by higher maximal mean power outputs for the shorter durations (ie, 5–30 s for flat stages and 30 s to 2 min for semimountainous stages) while mountain stage and TTs are characterized by higher relative maximal mean power outputs for the longer durations (ie, >10 min).[2] This is not entirely unexpected given that the typical key performance indicators that are mentioned in Table 1 are strongly influenced by the stage type. For example, flat stages (with a flat finish) often end in a mass sprint finish which is characterized by a high-speed lead into the last kilometers of the stage and ultimately ends with the (lead) sprinter of each team eliciting a maximal sprint lasting between 10 and 15 seconds

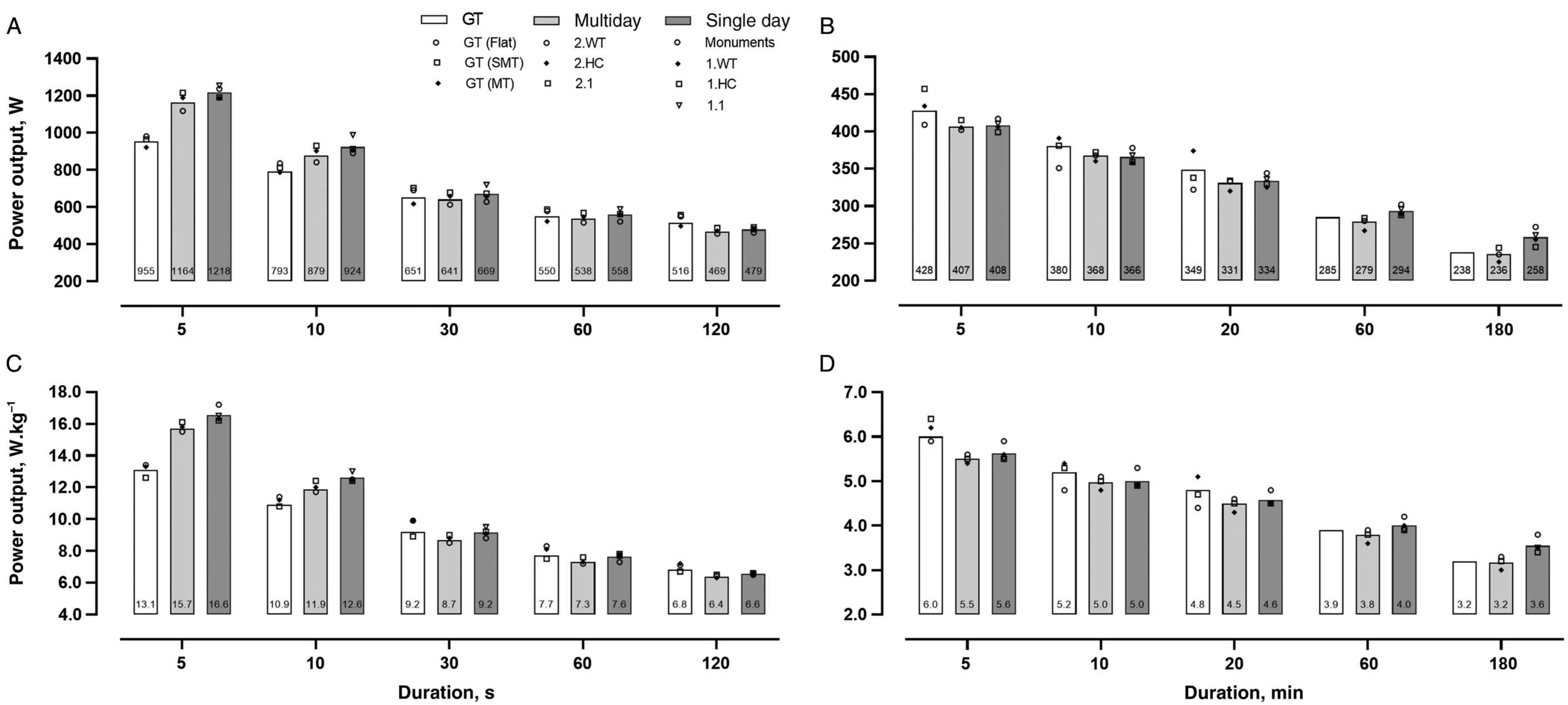


**Figure 2** — Reported absolute (A, B) and relative (C, D) maximum mean power outputs over different durations reported in the literature for Grand Tours, single-day races, and multiday races.[2,3,20,27] Monuments include Milan–San Remo, Tour of Flanders, Paris–Roubaix, Liege–Bastogne–Liege, and Giro Di Lombardia. Please note that the team analyzed for the GT stages[2] had a particular focus on stages with high elevation gain and less focus on sprint stages, therefore resulting in lower power outputs over short durations (ie, 5 and 10 s). Flat indicates flat stages; GT, Grand Tour; HC, Hors Catégorie; M, mountain stages; SMT, semimountainous stages; WT, World Tour; .1, category 1 races; 1., single-day races; 2., multiday races.

to the line (eg, observed sprint duration in a World Class road sprinter was approximately 10–11 s[11]). Even though not the whole peloton would elicit such a maximal sprint effort, the lead into the finish of such stages is characterized by multiple short-duration, high-intensity bursts thereby leading to the higher maximal mean power outputs from 5 to 30 seconds observed in flat stages. In contrast, a key performance indicator in a mountain stage is the ability to produce high relative power outputs for extended durations (>10 min) given the long uphill sections typically present within such stages. Expectedly, this will then also be present within the power profile of such stages and it can be seen from Figure 2 that mountain stages present with higher absolute and relative power outputs over longer durations compared with flat and semimountainous stages. Nevertheless, although trends are clearly visible between the different race types, larger differences can occur within the same race type.[3] The reported power profiles in the literature, which describes the demands of a certain stage type, are mostly values from several cyclists or a team. While such trends provide a good starting point and can indicate the relative importance of selected power–duration parameters for a certain stage type, it does not always give the complete picture for a rider or team with differing race goals and roles. For example, when a team brings a sprinter as team leader (including domestiques to "help" the sprinter), they will try to recover during the mountain stages and thus this will result in lower maximum mean power outputs for the longer durations when competing in these mountain stages.

In general, it seems that the power profile is influenced by the number of race days. As shown in Figure 2, single-day races tend to have higher power outputs for all the durations compared with multiday races. Like, previously mentioned, those differences are probably caused by different tactics and strategies used within those races as success in multiday stage races require a stable and high-performance level spread out over multiple days while this is obviously not the case for a single-day race. Therefore, single-day races are more suitable for an aggressive race style compared with multiday races which will result in higher maximum mean power outputs over different durations. There is currently a limited amount of research evaluating the potential drop in maximal mean power outputs across the later stages of races with an extensive amount of race days (eg, during a Grand Tour). However, it does seem that the race category (eg, World Tour vs category 1 races) influences the mean maximum power outputs of the race.[20] Surprisingly, lower-ranked races tend to have higher power outputs for shorter durations (<2 min), while the higher-ranked races have higher power outputs for the longer durations (>10 min) with the cycling "Monuments" presenting with the highest power outputs over long durations. It is suggested that the higher volume (ie, duration and distance) in the higher-ranked races may lead to additional fatigue toward the end of the races and this may blunt the power outputs of shorter durations.

## Practical Applications, the Missing Pieces of the Puzzle, and Limitations of Current Reporting

The previous sections, including the presented results, have aimed to provide an overview of the current evidence base in the scientific literature regarding the intensity and load demands and power profile of male professional cycling races. However, for practitioners, there are some important considerations to be aware of with regard to the interpretation of such data, which we have aimed to illustrate throughout the article but would like to highlight to a greater extent within this section. First, some limitations to the presentation of such data are important to be considered. The main limitation, partly due to the nature of (reporting within) scientific publications, is the presentation of mean or grouped data to reflect race characteristics while this may not "paint the full picture" on the demands of a particular race or group of races. For example, when the intensity of flat stages is reported to have a %mean $HR_{max}$ of 66% on average (Table 2), this can obviously still mean that there are flat stages that have a much higher (or lower) intensity than this number. The same goes for the other reported variables within this review (ie, load and power profile); while the mean number provides a good insight and starting point, this may not provide "worst-case scenario" or "race-winning effort" that practitioners aim to prepare their athletes toward. For example, while mountain stages might have an average 20-minute maximal mean power of 5.1 $W{\cdot}kg^{-1}$ based on a scientific article,[2] the number to be successful in these stages is substantially higher.[27] Furthermore, this mean number does not say anything about the repeatability of such efforts within a stage. However, there are some studies reporting this in greater detail. For example, van Erp et al[27] recently published a case study that shows the power profile of a rider being successful in winning a Grand Tour. Furthermore, Menaspa et al[48] investigated the differences in power profile between a top-10 and non-top-10 result during the World Cup race in professional female cyclists, providing some indications on the difference in demands between being "successful" and "not successful." Nevertheless, the overall research base with regard to "race-winning efforts" or "worst-case scenarios" on an individual level and in a variety of cycling categories is limited, and more research should be performed within this area. It must be acknowledged, however, that data on such race-winning efforts in professional cycling are often only available to practitioners working within such professional settings and their priority with regard to scientific publications might be low or they might be less prone to publish such data as they might feel it provides them with a competitive advantage.

Increasing the knowledge on "race-winning efforts" (eg, "What is the typical relative 20-min maximal mean power achieved of a cyclist winning an uphill finish?") would be an important step forward in the research on professional cycling (race) characteristics. Nevertheless, simply looking at "one number" (eg, 20 min $W{\cdot}kg^{-1}$) within a race, still does not provide the additional context around that number. Therefore, while this review described the intensity, load, and power profile of professional cycling races in separate sections, the recommendation for practitioners would be to analyze a race using a combination of metrics to "paint the full picture." For example, let us say we are evaluating a mountain stage of a rider and the 20-minute maximal mean power output measured was 5.8 $W{\cdot}kg^{-1}$. There are still several contextual factors around this number that are relevant to consider on an individual level: (1) Was this effort done in the beginning, middle, or the end of the stage? (2) What was the intensity within the stage prior to this effort? (3) What was the load accumulated in the previous days? (eg, Was this done in the first or last week of a Grand Tour?). Basically, intensity and load measures are needed to provide the context around this observed number of 5.8 $W{\cdot}kg^{-1}$ in order to get the full picture. This is nicely illustrated by the case study mentioned previously of a Grand Tour winning professional cyclist.[27] This article showed that a multitude of variables (eg, exercise load preceding the "effort") will influence the power output achieved on a mountain within a stage, advocating a multivariate approach in analyzing power profile data. Furthermore, Sanders et al[14] showed that throughout a Grand Tour, as a result of the accumulating fatigue due to the high daily load, a divergence in internal (eg, HR and RPE) and external (eg, power output) responses can be seen. For example, regression analysis showed that for the same TSS of 300 AU in the third week of a Grand Tour, sRPE can be approximately 400 units higher. Therefore, it is important to consider that interpreting the same variable with a different "fatigue state" can provide substantially different results, which should be considered when aiming to make practical inferences based on the data. Hence, the recommendation for practitioners is to combine a variety of metrics (ie, intensity, load, and power profile) to interpret data within the right context and to use that information to inform training and testing practices. To illustrate this, we have presented the (limited) research in cycling that reports data of an effort leading to "success," including the contextual factors around the effort in Table 3. Such approaches are advocated for practitioners and also as an important area of future research.

## Conclusion

An increasing amount of descriptive studies have provided insight into the (mean) physical demands and characteristics of male professional cycling races, and this review aimed to provide an updated overview of the current evidence base. The following key points were illustrated throughout this review: (1) the effect of stage type, particularly elevation gain, on the intensity and load characteristics of professional cycling races; (2) the effect of stage type on the maximal mean power output "fingerprint"; and (3) the effect of race length (ie, single-day vs multiday races) on the intensity and load demands and power profile of professional cycling races. This review also highlighted that there is currently a limited amount of research available describing the "race-winning efforts" in professional cycling races and this is indicated as an important area for future research. Finally, it is important for practitioners to consider the limitations of each metric individually, and a multivariable approach to analyzing races is advocated.

**Table 3 Research Providing Evidence on Data Leading to "Success" in Professional Cycling Settings Including Contextual Data Around the Effort**

| Reference | Subject group | Races/results | Reported data of effort leading to "success," mean (SD); range | Contextual data around the "successful effort," mean (SD); range |
|---|---|---|---|---|
| Menaspa et al[49] | 6 male professional road sprint cyclists | 17 races (sprint finish) within top 5 | Mean sprint duration (s): 13.2 (2.3); 9.0–17.0<br>PO whole sprint (W): 1020 (77); 865–1140<br>PO whole sprint ($W \cdot kg^{-1}$): 14.2 (1.1); 12.2–15.8<br>Peak PO data sprint (W): 1248 (22); 989–1443<br>Peak PO data sprint ($W \cdot kg^{-1}$): 17.4 (1.7); 13.9–20.0 | PO 10 min before the sprint (W): 316 (43); 231–424<br>TEG 10 min before the sprint (m): 27 (37); 0–152<br>PO 5 min before the sprint (W): 363 (38); 273–438<br>TEG 5 min before the sprint (m): 15 (19); 0–59<br>PO 1 min before the sprint (W): 487 (58); 409–593<br>TEG 1 min before the sprint (m): 3 (6); 0–25 |
| Menaspa et al[48] | 7 female professional cyclists competing at the highest level | 49 World Cup races; 25 times finishing in T10 and 24 finishes N-T10 | 5-s maximal mean PO for T10 ($W \cdot kg^{-1}$): 13.4 (1.3); 12.9–14.0<br>5-s maximal mean PO for N-T10 ($W \cdot kg^{-1}$): 12.5 (1.2); 12.0–13.0<br>1-min maximal mean PO for T10 ($W \cdot kg^{-1}$): 7.9 (0.7); 7.7–8.2<br>1-min maximal mean PO for N-T10 ($W \cdot kg^{-1}$): 6.9 (0.7); 6.7–7.2<br>5-min maximal mean PO for T10 ($W \cdot kg^{-1}$): 5.5 (0.5); 5.3–5.7<br>5-min maximal mean PO for N-T10 ($W \cdot kg^{-1}$): 5.1 (0.4); 5.0–5.3 | T10 race characteristics: 128 (7) km, 3 h 26 min (14 min) and 904 (551) m elevation gain<br>N-T10 race characteristics: 129 (8) km, 3 h 29 min (17 min) and 1020 (486) m elevation gain<br>T10 spent more time in the 6.75–7.50 $W \cdot kg^{-1}$ power band than N-T10. The N-T10 spent more time in the 3.01–3.75 $W \cdot kg^{-1}$ power band compared with T10<br>Significantly higher number of short- and high-intensity efforts (ie, ≥10 s, >7.5 $W \cdot kg^{-1}$) in T10 compared with N-T10 |
| van Erp et al[27] | 1 male Grand Tour winning professional cyclist | 4 Grand Tours analyzed—finishing between first and sixth in GC | All Grand Tours combined:<br>5-min maximal mean PO ($W \cdot kg^{-1}$): 6.6–7.2<br>10-min maximal mean PO ($W \cdot kg^{-1}$): 6.3–6.8<br>20-min maximal mean PO ($W \cdot kg^{-1}$): 6.0–6.2 | Elevation gain before each key climb influences the PO achieved on that climb. For every 1000 m of elevation gain before the key climb the PO drops with 0.23 $W \cdot kg^{-1}$ |

Abbreviations: GC, general classification; N-T10, non-top-10; PO, power output; T10, top-10; TEG, total elevation gain.

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