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Case Report: Load, Intensity, and Performance Characteristics in Multiple Grand Tours

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ABSTRACT

VAN ERP, T., M. HOOZEMANS, C. FOSTER, and J. J. DE KONING. Case Report: Load, Intensity, and Performance Characteristics in Multiple Grand Tours. *Med. Sci. Sports Exerc.*, Vol. 52, No. 4, pp. 868–875, 2020. **Introduction:** The aim of this study was to present the load, intensity, and performance characteristics of a general classification (GC) contender during multiple grand tours (GTs). This study also investigated which factors influence climbing performance. **Methods:** Power output (PO) data were collected from a GC contender from the Vuelta a España 2015, the Giro d'Italia 2017, the Giro d'Italia 2018, and the Tour de France 2018. Load (e.g., Training Stress Score and kJ spent) and intensity in five PO zones were quantified. One-way ANOVA was used to identify differences between the GTs. Furthermore, performance during the four GTs was quantified based on maximal mean PO ($W \cdot kg^{-1}$) over different durations and by the relative PO ($W \cdot kg^{-1}$) on the key mountains in the GTs. Stepwise multiple regression analysis was used to identify which factors influence relative PO on the key mountains. **Results:** No significant differences were found between load and intensity characteristics between the four GTs, with the exception that during the Giro d'Italia 2018, a significantly lower absolute time was spent in PO zone 5 ($P = 0.005$) compared with the other three GTs. The average relative PO on the key mountains ($n = 33$) was 5.9 ± 0.6 $W \cdot kg^{-1}$ and was negatively influenced by the duration of the climb and the total elevation gain before the key mountain, whereas the gradient of the mountain had a positive effect on relative PO. **Conclusions:** The physiological load imposed on a GC contender did not differ between multiple GTs. Climbing performance was influenced by short-term fatigue induced by previous altitude meters in the stage and the duration and gradient of the mountain. **Key Words:** GENERAL CLASSIFICATION CONTENDER, PROFESSIONAL, TEAM LEADER, PERFORMANCE, POWER OUTPUT

Elite road cycling is one of the most physically demanding sports in the world, especially the 3-wk multistage races: the Giro d'Italia, the Tour de France, and the Vuelta a España. A grand tour (GT) typically contains 21 race-days with only two or three rest days, covering between 3500 and 4000 km in 85–95 h of competition (1). For elite cyclists, to participate in one of the three GTs is the highlight of the season and winning a GT is the highest achievement possible in professional cycling. A GT is a complex race with different competition elements and therefore different kinds of stages (e.g., flat, semimountainous, and mountain stages) (2,3).

The introduction of the heart rate and power output (PO) monitors ensures that more information on the load and intensity demands of participating in a GT is obtained (2–8). In 2003, Lucia et al. (4) showed with heart rate data of seven cyclists the load and intensity demands of two different GTs (the Tour de France and the Vuelta a España) and did not find any significant differences between the load and intensity despite the assumed different nature of both races. Vogt et al. (2) and Sanders and Heijboer (3) discussed, on the basis of heart rate and PO, the load and intensity characteristics of different terrains (e.g., flat, semimountain, and mountain stage) in GTs (2,3). In addition, Rodriguez-Marroyo et al. (5) showed that fatigue suppresses the heart rate during a GT and was able to correct the load and intensity demands of the Vuelta a España by adjusting heart rate thresholds based on prelaboratory and postlaboratory tests. Although multiple studies report load and intensity characteristics of GTs, it is still unknown what the load and intensities are for a General Classification (GC) contender.

Winning a GT is the highest achievement possible for an elite cyclist and only accomplished by the best and most complete cyclists. With exceptions from (team) time trials (TTs), differences in the GCs are mostly made by performances uphill, which can be defined by the relative PO during that climb. Therefore, relative PO on the last mountain in a stage is very important for a GC contender. Pinot and Grappe (9) presented

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the relative mean maximal PO over different durations (15–18,000 s), the so-called record PO (9) or maximal power profile (MPP) (10) of a GC contender achieved in training and competition. In addition, Sanders and Heijboer (3) presented the MPP values of nine riders during the Giro d'Italia. Both studies give a rare glimpse of the performances necessary to compete in a GT. However, PO values on the key mountains for a GC contender in a GT are still unknown.

Several factors can influence the performance of GC contender on the key mountains during a GT. Because of the very demanding nature of GTs, elite cyclists accumulate fatigue over the 3 wk of racing, and this may reflect in several physiological and psychological changes that affect performance (4,11–13). Recently, Rodriguez-Marroyo et al. (5) showed that long-term fatigue accumulated by professional cyclists over 21 d of racing resulted in a performance decline of ~10% and affected maximal and submaximal endurance performance. Furthermore, it is expected that fatigue sustained during the stage (short-term fatigue) has an influence on the performance at the end of a stage (14). Furthermore, mountain characteristics such as the length and the gradient of the mountain will have an influence on the performance and thus on relative PO (7,15). Lastly, environmental conditions such as heat (16) and altitude (17) could impair performances.

Although there is growing interest in the load, intensity, and performance characteristics of elite cyclists competing in GTs (2–5), the reported values in the literature are based on the average of multiple cyclists. In GTs, teams select different types of riders, which have different roles throughout the race (e.g., sprinter, domestic, and TT specialist) and thus do not have to perform all 21 stages at their top level (18,19). This contrasts with a GC contender who must perform every day to prevent losses in time. Therefore, load and intensity demands for a GC contender could be higher than the reported values for the average team. However, there is evidence of "pacing" across the duration of GTs, whereby GC riders only ride at maximal effort during a few stages (20). In addition, to the best of the authors' knowledge, no study reported performance characteristics of a GC contender or factors that could influence the performance of a GC contender during a GT. Therefore, our research question was threefold: first, to present the load and intensity characteristics of a GC contender for multiple GTs; second, to present the relative PO, which is needed on the key mountains to compete for the victory in multiple GTs; and third, to examine which factors are associated with the relative PO on the key mountains.

METHODS

Participant. The athlete is a professional cyclist (24 yr, 69.9 kg, 185 cm) competing in the Union Cycliste Internationale World Tour Series and provided written informed consent for a detailed analysis of his PO data collected during the Vuelta a España 2015, the Giro d'Italia 2017, the Giro d'Italia 2018, and the Tour de France 2018, where the athlete competed for the GC victory. During the 7 yr that the athlete was a professional cyclist, he was highly successful and in 2017 and 2018 ranked as a top 10 cyclist in the world according to the World Tour ranking. The main specialty of the athlete are TTs, where he became World Champion in 2017 (individual and team TT) and won a silver medal at the 2016 Olympics. Furthermore, the athlete won 2 GCs in the World Tour, a 7-d race: the BinckBank Tour in 2017 and the Giro d'Italia in 2017. Until 2019, the athlete won 19 races including TTs and road races in all the GTs.

Research design. During four GTs, PO data were collected from as many as possible stages and uploaded to a central database. Because of sponsor changes, the collection of the PO data was done with different brands of power meters and with different power meters on different bikes (i.e., one road bicycle, two reserve road bicycles, and two TT bicycles). The PO data from the Vuelta a España 2015 and the Giro d'Italia 2017 were collected by Pioneer power meters (SGY-PM910H2; Pioneer, Kawasaki, Japan) and from the Giro d'Italia 2018 and the Tour de France 2018 by Shimano power meter (FC-RC9100-P; Shimano, Sakia, Japan). The athlete and mechanics were informed about the importance of the zero calibration and were instructed to do the zero calibration before every ride. Because of malfunctions, crashes and bicycle changes PO data were not recorded for two stages at the Vuelta a España 2015 (i.e., stages 9 and 19), two stages at the Giro d'Italia 2017 (i.e., stages 3 and 4), two stages at the Giro d'Italia 2018 (i.e., stages 4 and 21), and two stages at the Tour de France 2018 (i.e., stages 2 and 13). All collected PO data were manually checked, and spikes were manually corrected when necessary. Data were sampled at 1 Hz during the Vuelta a España 2015, the Giro d'Italia 2017, and the Tour de France 2018. Using another bicycle computer during the Giro d'Italia 2018, the data were collected at 0.2 Hz. All bicycle computers measured race characteristics (i.e., distance, duration, and elevation (gain)) and environmental characteristics (i.e., temperature).

Load and intensity characteristics. Load characteristics are based on PO and measured as the total mechanical energy spent (in kilojoules spent) and Training Stress Score (TSS). (10) TSS was calculated according to equation 1.

$$\mathrm{TSS} = \left(\frac{t \times \mathrm{NP} \times \mathrm{IF}}{\mathrm{FTP} \times 3600}\right) \times 100 \qquad [1]$$

where t is the duration of the race in seconds and IF the intensity factor (see equation 3). NP is the normalized power as calculated with equation 2, where p_i is the floating mean power for 30-s time segments and N is the total number of time segments. The functional threshold power (FTP) was determined as 95% of the highest 20-min mean maximal PO obtained in races from that particular season (10). FTP was established at 408 W (5.8 W·kg^{-1}) for the Vuelta a España 2015, 409 W (5.8 W·kg^{-1}) for the Giro d'Italia 2017, 417 W (5.9 W·kg^{-1}) for the Giro d'Italia 2018, and 417 W (6.0 W·kg^{-1}) for the Tour de France 2018.

$$\mathrm{NP} = \sqrt[4]{\frac{1}{N}\sum_{i=1}^{N} p_i^4} \qquad [2]$$

$$\mathrm{IF} = \left(\frac{\mathrm{NP}}{\mathrm{FTP}}\right) \qquad [3]$$

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In addition, similar to previous research (21,22), load metrics (TSS and kJ spent) are expressed relatively per kilometer (kJ spent·km^{-1} and TSS·km^{-1}). Intensity distribution was quantified based on the time spent in five different PO zones. The five PO zones were based on a percentage of FTP based on guidelines provided by Allen and Coggan (10): zone 1, ≤55% of FTP; zone 2, 56%–75% FTP; zone 3, 76%–90% FTP; zone 4, 91%–105% FTP; and zone 5, ≥106% FTP.

Performance characteristics. To assess the performance during the four GTs, the MPP and the relative PO on the key mountains were analyzed. The MPP corresponded to the highest mean maximal power developed in each GT by the athlete for the durations of 5, 10, and 30 s and 1, 5, 10, 20, 60, 120, and 180 min. The MPP was expressed in relation to body mass of the cyclist (W·kg^{-1}) to compensate for changes in body mass. Body mass was measured by the team for the four GTs, and the mean body masses were 69.9, 70.3, 70.5, and 69.0 kg for the Vuelta a España 2015, the Giro d'Italia 2017, the Giro d'Italia 2018, and the Tour de France 2018, respectively.

To analyze the performance on the key mountains in the GTs, the last mountain in a stage with an uphill finish and mountains with a significant importance (e.g., finish directly after descend) were selected by the use of www.touretappe.nl (23) and www.procyclingstats.com. (24) Based on visual inspection of the PO, speed, and altitude data, the key mountains were manually selected and PO data were collected and expressed in relation to the athlete's body mass (W·kg^{-1}).

Factors that influence performance. To investigate the effect of long-term fatigue on the climbing performance at the key mountains, we reported on which race-day the key mountains were in the GT (stage number). To determine the effect of short-term fatigue during the stage, the duration, distance, total elevation gain (TEG), kJ spent, TSS, kJ spent·km^{-1}, and TSS·km^{-1} were measured from the start of the stage till the start of the key mountain. Furthermore, to investigate the influence of mountain characteristics on relative PO, we measured the duration and the gradient of the key mountains. Finally, the temperature and average altitude measured by the bike computer on the key mountain were analyzed to investigate the effect of heat stress and altitude on climbing performance.

Statistical analysis. Descriptive data were reported as mean (±SD). All parameters except stage number were collected by analyzing the collected PO data from the four GTs. Differences between the four GTs were determined using one-way ANOVA. Bonferroni's *post hoc* test was applied to identify differences when the ANOVA indicated a significant main effect. Stepwise multiple linear regression (SMLR) analysis was used to identify the best predictors of the relative PO on the key mountains. Before SMLR, the collinearity between variables was determined by Pearson correlations. For variables with a correlation of $r > 0.7$, the variable with the highest correlation with performance (relative PO on the key mountain) was used for SMLR. Based on a visual inspection of the relation between duration of the climb and relative PO, duration was logarithmically transformed for better fitting the data. Regression coefficients (intercept and slopes) are presented, and uncertainties in the coefficients are presented as 95% confidence intervals (CI). PO analysis was performed using Golden Cheetah (Golden Cheetah, Version 3.4), and statistical analysis was performed using SPSS (IBM SPSS Statistics version 23; IBM Corporation, Armonk, NY). The level of statistical significance was set at $P < 0.05$. The following criteria were adopted to interpret the magnitude of the correlation (r) between the measures: <0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; and >0.5, large (25).

RESULTS

In total, 76 stages were analyzed, which were collected during the Vuelta a España 2015 (n = 19), the Giro d'Italia 2017 (n = 19), the Giro d'Italia 2018 (n = 19), and the Tour de France 2018 (n = 19). In the GCs, the athlete finished sixth, first, second, and second, respectively. In total, the athlete finished in 14 stages in the top 3, from which he won 6 stages (two road races and four TTs) and was GC leader for 5, 9, and 1 d in the Vuelta a España 2015, the Giro d'Italia 2017, and the Giro d'Italia 2018, respectively.

Table 1 presents basic descriptive and load characteristics for the four GTs. No significant differences were observed between the four GTs. The GT with the lowest load recorded was the Tour de France 2018 and the highest load recorded was the Giro d'Italia 2018; the differences between both of them were 6% and 11% for kJ spent and TSS, respectively.

Figure 1 presents the relative and absolute time spent in the five PO zones. *Post hoc* test analyses revealed a lower absolute time spent in PO zone 5 during the Giro d'Italia 2018 (334 ± 8 min) compared with the Vuelta a España 2015 (531 ± 9 min; P = 0.005), the Giro d'Italia 2017 (533 ± 11 min; P = 0.005), and the Tour de France 2018 (493 ± 9 min; P = 0.039). No significant differences were observed between the other PO zones in the four GTs.

TABLE 1. Average load and intensity characteristics for the GTs where the athlete competed for the GC victory (mean ± SD).

	Vuelta a España 2015 (*n* Stages = 19)	Giro d'Italia 2017 (*n* Stages =19)	Giro d'Italia 2018 (*n* Stages =19)	Tour de France 2018 (*n* Stages =19)
Distance, km	168 ± 53.5	181 ± 55.1	176 ± 58.2	167 ± 55.4
Duration, min	260 ± 85	272 ± 95	266 ± 91	255 ± 86
PO, W	227 ± 36.2	203 ± 43.2	238 ± 47.2	228 ± 36.5
PO, W·kg^{-1}	3.25 ± 0.52	2.89 ± 0.61	3.38 ± 0.67	3.30 ± 0.53
TEG, m	2413 ± 1397	2583 ± 1438	2245 ± 14784	2076 ± 1436
Total kJ spent, kJ	3623 ± 1196	3643 ± 1185	3770 ± 1359	3530 ± 1192
Total TSS™	233 ± 80.5	237 ± 84.9	234 ± 91.6	209 ± 74.6
kJ spent·km^{-1}	22.4 ± 4.8	21.4 ± 5.9	24.0 ± 11.7	22.7 ± 7.6
TSS·km^{-1}	1.48 ± 0.46	1.48 ± 0.75	1.39 ± 0.38	1.38 ± 0.60

No significant difference between GTs is found (P > 0.05).
Norm, normalized.

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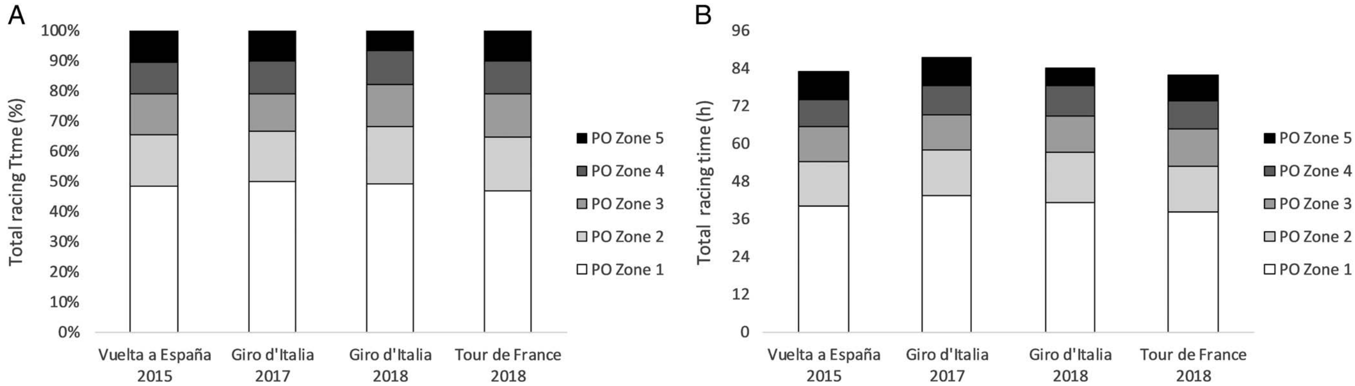

FIGURE 1—Intensity distribution expressed as relative (A) and absolute (B) time spent in different PO zones in a GC contender during different GTs. Absolute time spent in PO zone 5 during the Giro d'Italia 2018 is significantly (P < 0.05) different from the other GTs.

Figures 2 and 3 and Table 2 give a detailed overview of the athlete's performance during the four GTs. Figure 2 presents the relative MPP (5, 10, and 30 s and 1, 5, 10, 20, 60, 120, and 180 min), and Figure 3 presents the relative PO of all key mountains. Table 2 provides a summary of the key mountains and the mountain characteristics. The average relative PO on all the key mountains for all four GTs combined was 5.9 ± 0.6 W·kg^{-1}.

Table 3 presents the correlation matrix between all the factors with a moderate correlation with relative PO on the key mountain or factors identified by SMLR. SMLR analysis showed that in the final regression model climbing performance was significantly associated with a combination of the duration ($\log_{10}$ transformed; −1.52 W·kg^{-1} (95% CI, −1.81 to −1.22), r^2 = 0.61, P = 0.0001), the TEG before the mountain (·10^{-3}); −0.23 W·kg^{-1} (95% CI, −0.32 to −0.14), r^2 = 0.13, P = 0.0001), and gradient of the mountain (0.12 W·kg^{-1} (95% CI, 0.07 to 0.17), r^2 = 0.11, P = 0.0001), whereas the intercept was 7.64 W·kg^{-1} (95% CI, 7.11 to 8.17). A total of 86% of the variance of the relative PO on the key mountain can be explained by those three factors, described in equation 4.

$$\begin{aligned}\mathrm{PO}\left(\mathrm{W{\cdot}kg^{-1}}\right) = {} & 7.64 + \log_{10}(\text{duration mountain (min)}) \\ & \times (-1.52 + \text{ gradient mountain } (\%)) \\ & \times (0.12 - (\text{TEG before mountain (m)} \times 10^{-3})) \times 0.23 \end{aligned} \quad [4]$$

DISCUSSION

This is, to the authors' knowledge, the first study describing the individual load, intensity, and performance characteristics of a GC contender during multiple GTs. The presented data cover one GT in which the athlete finished first and two GTs where the athlete finished second. Therefore, the present study gives a unique insight into the load, intensity, and performance characteristics of the fight for a GT victory. Furthermore, SMLR analysis showed that the climbing duration and the gradient of the key mountain combined with indicators of short-term fatigue determined 86% of the variance of the relative PO on the key mountain.

Load and intensity. An impressive energy expenditure during racing between 74,123 and 79,166 kJ or a TSS between 4400 and 4983 au is necessary to finish a GT in the top 10. Similar to Lucia et al. (4), this study did not find any significant differences between the load of the four GTs despite the fact that all GTs have different combinations of flat, semimountain, and mountain stages and (team) TTs. The largest load differences occurred between the Giro d'Italia 2018 and Tour de France 2018, which was 6% and 11% for kJ spent and TSS, respectively. The differences between kJ spent and TSS are probably caused by the quadratic relation with exercise intensity, which is integrated within the calculation of TSS (26). Our data showed that despite competing for the GC, ~80% of the time in

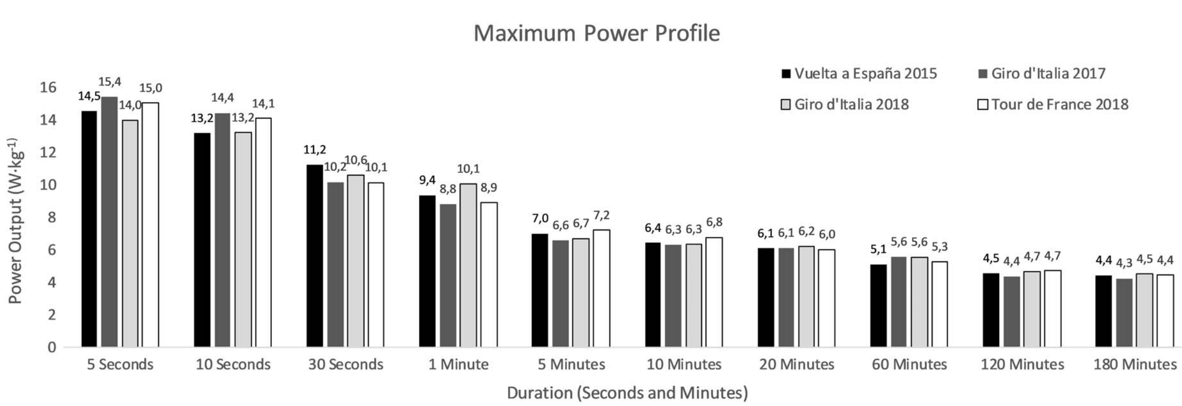

FIGURE 2—MPP from a GC contender during different GTs. The values indicate the maximal PO for different durations (5, 10, and 30 s and 1, 5, 10, 20, 60, 120, and 180 min) achieved in the GTs participated by the athlete and are expressed in relation to the body mass of the athlete.

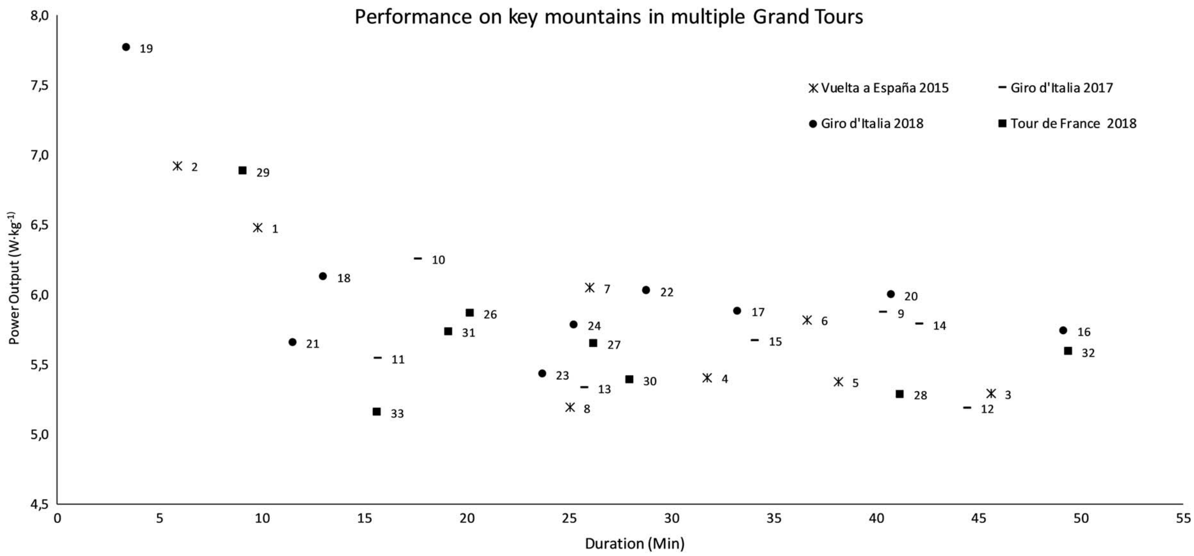

FIGURE 3—Relative PO at different key mountains in a GC contender during multiple GTs (Alto de la Mesa[1]; Alto de Cazorla[2], Alto de Capileira[3], Alto Els Cortals d'Encamp[4], Alto Campoo[5], Alto de Sotres[6], Alto Ermita de Alba[7], Puerto de Cotos[8], Blockhaus[9], Oropa[10], Selvino[11], Umbrailpass[12], Pontives[13], Piancavallo[14], Asiogo[15], Etna[16], Montevergine di Mercogliano[17], Gran Sasso d'Italia[18], Osimo[19], Zoncolan[20], Sappada[21], Pratonevoso[22], Bardonecchia[23], Cervinia[24], Mur d Bretagne[25], Col de la Colombiere[26], La Rosiere[27], Alpe d'Huez[28], Mende[29], Pic du Nore[30], Col du Portillon[31], Saint-lary Soulan[32], Col d'Aubisque[33]).

a GT is spent in the low-intensity zones (PO zones 1, 2, and 3). Furthermore, ~10% is spent around FTP (PO zone 4) and ~10% is spent in the highest PO zone or above FTP (PO zone 5). The only significant difference found between the four analyzed GTs was a lower absolute time spent in PO zone 5 during the Giro d'Italia 2018 (334 ± 8.3 min) compared with the other three GTs. The lack of significant different load and intensity between the four analyzed GTs could suggest that GC contenders unconsciously pace their efforts during a GT (4,20). For example, the Giro d'Italia 2017 had the highest amount of distance, duration, and TEG, whereas the PO, intensity factor, and kJ spent·km^{-1} were the lowest of all the four studied GTs. The lower time spent in PO zone 5 during the Giro d'Italia 2018 could be caused by the higher overall pace during this GT. This is shown by the higher PO and intensity factor. This is strengthened by the results of the regression analysis that TEG before the key mountain had a decremental effect on relative PO. A high amount of elevation gains in a GT results in a lower PO on the key mountains and thus a lower load and intensity on the key mountains. This will result in an overall lower load and intensity demand for the specific GT. This is in agreement with Lucia et al. (4), who stated that a shorter or less mountainous GT is compensated by a higher relative intensity compared with a GT that covers a lot of kilometers or altitude meters.

Performances. Reported MPP values in this study are higher compared with the values reported by Sanders and Heijboer (3), which is probably caused by averaging the values of a whole team (Fig. 2). Cyclists have different roles during a GT (e.g., domestique, sprinter, GC contender, and TT specialist), and different roles mean different priorities. For example, a GC contender must perform at his maximal on some moments during all the 21 stages, whereas sprinters and their domestiques pace mountain stages to be within the time limit and therefore do not have to compete maximal every stage. Thus, averaging MPP values of GC contender and domestiques will result in lower MPP values compared with MPP values of a GC contender alone. In agreement with Pinot and Grappe (9), the term "record PO" is preferred to describe performance instead of "mean maximal PO," because the highest PO obtained during competition is not the maximal that can be achieved by the athlete. This could also be the reason why the values reported in this study are slightly lower compared with Pinot and Grappe (9). The MPP values presented in this study were affected by fatigue, tactical racing, and the ability to achieve a maximal effort exactly for each duration, whereas MPP values achieved during training are not influenced by the factors mentioned previously (Fig. 2). For the first time, climbing performances of a GC contender in a GT are described. On average, an impressive 5.9 ± 0.6 W·kg^{-1} for 27 ± 13 min is necessary on the key mountains to compete for the GC victory. The presented data are from a GC contender specialized in TTs, and thus, he gained time on his direct competitor (i.e., first or second place in the GT) in the specific GTs during those TTs (i.e., 113, 257, 50, and 14 s, in the respective GTs). Therefore, this GC contender can have a more defensive race strategy throughout the mountain stages because his strategy is not to lose time in these stages and gain time during the TTs. Thus, it could be that the described climbing values are even

TABLE 2. Mountain characteristics and PO from the key mountains for the GTs where the athlete competed for the GC victory (mean ± SD).

	Vuelta a España 2015 (*n* = 8)	Giro d'Italia 2017 (*n* = 7)	Giro d'Italia 2018 (*n* = 9)	Tour de France 2018 (*n* = 9)
Distance, km	10.0 ± 6.0	11.0 ± 3.4	9.4 ± 4.3	8.4 ± 4.5
Duration, min	27.5 ± 13.8	31.5 ± 11.8	25.4 ± 12.4	23.7 ± 14.5
PO, W	407 ± 43.8	398 ± 25	427 ± 51	405 ± 50
PO, W·kg^{-1}	5.8 ± 0.6	5.7 ± 0.4	6.0 ± 0.7	5.9 ± 0.7
Gradient, %	7.8 ± 1.9	7.2 ± 1.1	7.0 ± 2.8	7.3 ± 1.6
Temperature, °C	23.7 ± 7.8	24.6 ± 2.6	17.1 ± 4.5	24.7 ± 3.4
Stage number	11.4 ± 6.0	15.9 ± 3.7	13.3 ± 4.6	13.3 ± 4.0
Altitude, m	1041 ± 464	982 ± 437	1192 ± 541	1118 ± 428

TABLE 3. Correlation matrix for parameters with a moderate ($r > 0.3$) association with performance on the key mountain or with a significant influence on performance based on stepwise multiple regression analysis.

	Performance	Mountain Characteristics			Long-Term Fatigue	Short-Term Fatigue		
	PO, W·kg^{-1}	Duration, Min	Gradient, %	Altitude, m	Stage Number	TEG	kJ Spent·km^{-1}	TSS·km^{-1}
Performance								
PO, W·kg^{-1}	—							
Mountain characteristics								
Duration, min	−0.78	—						
Gradient, %	0.27	0.11	—					
Altitude, m	−0.62	0.44	−0.02	—				
Long-term fatigue								
Stage number	−0.44	0.17	−0.06	0.30	—			
Short-term fatigue								
TEG	−0.45	0.03	0.09	0.63	0.23	—		
kJ spent·km^{-1}	−0.40	0.01	−0.01	0.55	0.26	0.72[a]	—	
TSS·km^{-1}	−0.40	−0.01	−0.08	0.49	0.29	0.72[a]	0.97[a]	—

Performance, the relative PO on the last mountain; Mountain characteristics, duration and gradient of the last mountain; Stage number, amount of days in the GT; Short-term fatigue, TEG, kJ spent·km^{-1}, and TSS·km^{-1} measured before the last mountain.
[a]A moderate or higher collinearity.

higher in GC contenders specialized in climbing. Furthermore, this GC contender was GC leader for multiple days in the Vuelta a España 2015 (5 d) and the Giro d'Italia 2017 (9 d). Defending the GC lead could result in a different race strategy, and thus a different MPP or intensity distribution, compared with a rider challenging the race leader.

Surprisingly, during the GT won by this athlete, the Giro d'Italia of 2017, the athlete had a slightly lower performance with 5.7 ± 0.4 W·kg^{-1} on the key mountains compared with the other GTs (Table 2). This could be explained by the results of the SMLR analyses. During this GT, the average duration on the key mountains was longer. As shown by SMLR analysis, duration has a large negative influence on the relative PO on the key mountains. It was expected that the duration of the mountain has a large influence on climbing performance as it is well established that PO is influenced by duration, described by the power–duration relationship (27,28). This power–duration relationship is also clearly visible in the MPP (Fig. 2). Surprisingly, from all the parameters to assess short-term fatigue, TEG before the key mountain has the largest influence on the performance on the key mountains, whereas load measurements before the key mountain (i.e., TSS and kJ spent) did not have any significant influence. However, load values expressed per kilometer (i.e., TSS·km^{-1} and kJ spent·km^{-1}) before the key mountain did show a moderate relationship with performance on the key mountains (Table 3). In addition, collinearity analysis showed that they could be interchangeable used for TEG before the key mountain in the SMLR analysis. Thus TSS·km^{-1} and kJ spent·km^{-1} may be good indicators for short-term fatigue. One of the reasons that relative load values (TSS·km^{-1} and kJ spent·km^{-1}) are better indictors for short-term fatigue compared with absolute load values may be that professional cyclists are highly endurance trained and a long low-intensity race will not cause the same amount of fatigue as a shorter high-intensity race. The load measurements relative to distance (TSS·km^{-1} and kJ spent·km^{-1}) are in line with previously reported measurements (3,22).

Furthermore, gradient had a large effect on the relative PO on the key mountain; 14.5% of variance of the PO was determined by the gradient of the mountain. A 1% increase in steepness means 0.12 W·kg^{-1} higher relative PO on the mountain. This is in agreement with Padilla et al. (7), which divided mountains during the three GTs into three categories based on the length and steepness and found higher PO on the steeper category mountains compared with the less steeper category mountains. One of the reasons could be that a steeper mountain means less drafting and thus less help from domestiques. Therefore, gradient of the mountain also influences race tactics, which indirectly influence PO. Furthermore, a mountain with a lower gradient could mean some flatter easier parts, and thus, a more stochastic PO as drafting behind domestiques has a bigger effect with high speeds.

One of the hypotheses of this study was that long-term fatigue (stage number) would influence the performances on the key mountain in a GT. However, stage number did not significantly ($P = 0.12$) influence relative PO on the key mountain. This is not in line with previous research that found a decrement of performances after a GT of ~10% comparing a laboratory exercise test before and after a GT in non-GC contenders (5). Although not significant, the SMLR analyses indicate a PO decrement of −0.015 W·kg^{-1}·d^{-1} in a GT, which means a difference of ~5% between a performance on the first day and the last day of a GT. One of the specific determinants of a successful GC contender is the ability to sustain accumulating load while holding a high-performance level. In the study of Rodriguez-Marroyo et al. (5), cyclists with different specialties (none GC contenders) were studied, which could be a reason for the lower decrement in performance described in this study. Furthermore, a GC contender is protected by domestiques throughout the whole GT to save energy. In addition, we assume that with a higher number of climbs, long-term fatigue will be of significant influence on the performance on the key mountain. Another reason that stage number did not significantly influence performance is that most GTs have their mountain stages in week 2 or week 3, and therefore, almost all performances analyzed in this study were already affected to some extent by long-term fatigue. Lastly, it could be that fatigue influences the race intensity before the key mountain and thus had a smaller effect on the performance on the last mountain.

Our hypothesis was that a high environmental temperature would negatively influence performance on the key mountain because it is well known that heat stress impairs performance (16). This study did not find any significant influence of temperature on performance on the key mountain. The reason for this could be that only four mountains were recorded with a temperature above 30°C. From those four mountains, two mountains were shorter than 10 min, and thus, heat stress would probably not influence the performance on those 2 mountains. Furthermore, we hypothesized that altitude will negatively influence the PO on the key mountains, as it is well known that hypoxia impairs performance (17). However, in the present study, we did not find any significant influence of altitude on the PO at the key mountains. From the 33 analyzed mountains, the average altitude was ~1000 m, from which only 7 mountains were on average above 1500 m. This could result in a decline in PO of approximately 5.3% and 8.7% at 1000 and 1500 m, respectively (29). However, the standard preparation of the athlete for a GT was a high-altitude training camp for a minimum of 14 d, which reduces the influence of altitude significantly to approximately 3.0% at 1000 m and 5.4% at 1500 m (29). Therefore, it is likely that the influence of altitude is somewhat limited because of acclimatization. Furthermore, race tactics and averaging the PO of the whole mountain could also blunt the effect of altitude.

Limitations. The presented data were primarily collected for monitoring of training load of the athlete and are therefore not without limitations. The measurements of PO were done with two different brands of power meters and the athlete had multiple bikes (one road bicycle, two reserve road bicycles, and two TT bicycles) during the GTs, and therefore, the presented data of the GTs were collected with different power meters. The mechanics of the team had the task to zero calibrate the power meter every day before the race, although the authors did not control this. Furthermore, within the team, no in-house calibration was performed after receiving the power meter from the manufacturers. Because of malfunctions, crashes, and bicycle changes, PO was not measured during eight stages divided equally over the four GTs. Furthermore, four different brands of bicycle computers were used to collect the altitude data which can influence the measurements of altitude (30). In addition, FTP was obtained by taking 95% of the highest 20-min mean maximal PO obtained during the particular season. Nimmerichter et al. (31) showed that variations within a season can be up to 0.4 $W \cdot kg^{-1}$. Furthermore, the correction factor of 95% is a somewhat arbitrary choice, and it is shown that a low or high anaerobic capacity has an influence on this correction factor (32). Both limitations of FTP could have an influence on the presented TSS values and intensity zones. Furthermore, ideally, PO intensity zones would be anchored around physiological thresholds, such as the first and second lactate or ventilatory thresholds (33,34). However, during the time of the data collection, no regular and controlled laboratory exercise testing was implemented within the team. Therefore, in this study, the boundaries of the intensity zones are based on Coggan and Allen (10), which are somewhat arbitrary chosen, and the boundaries are not equally spaced. This could influence the reported intensity distribution. Lastly, the key mountains were manually selected based on visual inspection of PO, speed, and altitude profile and could therefore be slightly different in length compared with the official length of the mountains.

CONCLUSIONS

To conclude, overall load and intensity characteristics in four different GTs did not differ when competing for the GC. An impressive 5.7 to 6.0 $W \cdot kg^{-1}$ on the key mountains is necessary to compete for the victory in multiple GTs. Short-term fatigue in combination with the gradient and duration of the climb determines 86% of the variance of the relative PO on the key mountains.

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