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Journal of Science & Cycling
Breakthroughs in Cycling & Triathlon Sciences

Original Article

Tour de Physiology: The Exceptional Power Outputs and $\dot{V}O_2$ of climbing in the Tour de France

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Received: 17 June 2025 **Accepted:** 8 November 2025 **Published:** 9 November 2025

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Abstract

The Tour de France stands as perhaps the most demanding endurance competition in the world, requiring athletes to sustain exceptional physiological performance over three weeks of racing. Central to success in this event is a remarkably high maximal oxygen uptake ($\dot{V}O_2$max). The 2024 and 2025 Tour de France showcased unprecedented climbing performances, with new records set on iconic ascents. This brief report analyzes the physiological demands of these performances by estimating the $\dot{V}O_2$ and power output required during six decisive climbs (Plateau de Beille, Isola 2000, Col de la Couillole, Hautacam, Peyragudes, Mont Ventoux) by the race winner, Tadej Pogačar. Using publicly available climb data, rider anthropometrics, and validated mechanical models of cycling power output, results indicate estimated mean power outputs of 442 ± 15 W and corresponding mean oxygen consumptions of 80 ± 3 mL·kg^{-1}·min^{-1} sustained over ~40 min. Extrapolating from these efforts and known relationships between critical power and $\dot{V}O_2$max suggests that Pogačar's $\dot{V}O_2$max during the race likely exceeded 90 mL·kg^{-1}·min^{-1}. These findings underscore the extraordinary aerobic capacity required to achieve record-breaking performances in Grand Tour cycling. They also highlight how ongoing improvements in training, equipment, and rider physiology continue to push the limits of human endurance performance to the enjoyment of the spectators.

Keywords

Cycling; Oxygen Consumption; Critical Power

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1 Introduction

The Tour de France is a yearly exhibition of perhaps the most elite endurance performance in the world. Over three weeks cyclists face repeated high-intensity efforts, cumulative fatigue, and strenuous climbs — all while maintaining competitive power outputs and proper technique (Lucia et al., 2001). Success in this event requires an extraordinary level of aerobic fitness, with maximal oxygen uptake ($\dot{V}O_2max$) serving as a cornerstone of performance capacity. While high $\dot{V}O_2max$ values are common among top-level endurance athletes, the $\dot{V}O_2max$ required to win the Tour de France is truly exceptional — often exceeding 80 $mL \cdot kg^{-1} \cdot min^{-1}$ in champions during their peak years (Coyle, 2005; Santalla et al., 2012).

Moreover, winning the Tour de France involves not only possessing a high $\dot{V}O_2max$ but also sustaining a high percentage of this capacity during prolonged stages, especially during mountain stages (Faria et al., 2005).

The 2024 and 2025 Tour de France displayed several exceptional feats of aerobic performance as we saw old record times at several climbs be smashed by the race winner. Notably, the winner of last year's race Tadej Pogačar delivered six stage wins during the 2024 race, and four stages in 2025, including several impressive climbing performances. This brief report aims to describe the exceptional work done and the aerobic capacity required for this performance.

2 Material and Methods

This study was conducted as a retrospective secondary analysis of public data and involved no direct contact with human subjects. All analyses were conducted with transparency and respect for data integrity.

Using rider information from team UAE's website anthropometrics of the cyclist Tadej Pogačar was collected (Emirates, 2025). Weight of the bike used at the climbing stages was noted from the specifications of equipment used.

The time and elevation gain for the 2024 climbs of Plateau de Beille (stage 15), Isola 2000 (stage 19), Col de la Couillole (stage 20) and 2025 Hautacam (stage 12), Peyragudes (stage 13), Mont Ventoux (stage 16) were collected from Strava results. Power output in watt to ascend in the given time was calculated as:

$$P_v = (TW \cdot 9{,}81 \cdot E) \cdot t^{-1}$$

where P_v is power (W) to conduct the work of vertical displacement, TW is total weight of rider and bike (kg), E is vertical elevation (m), and t is time to ascend the elevation gain (s). Average speed ($km \cdot h^{-1}$) of the climb was calculated by dividing the length of the climb with the time to ascend.

Adding to the power output of the elevation gain, the power output to overcome aerodynamic drag for the rider was computed assuming no wind and according to previous publications (Faria et al., 2005; Heil, 2005):

$$A = 0.0293 \cdot H^{0.725} \cdot W^{0.425} + 0.0604$$

$$C_d = 4.45 \cdot W^{-0.45}$$

$$C_dA = C_d \cdot A$$

$$P_a = ½ \cdot \varrho \cdot C_dA \cdot v^3$$

where A is frontal area in an aerodynamic position (m^2), H is rider height (m), W is rider body weight (kg), C_d is drag coefficient, ϱ is air density assumed to be a standard 1.225 kg/m^3, v is velocity (m/s), and P_a is the power (W) to overcome the aerodynamic drag.

Rolling resistance was calculated as:

$$P_r = C_{rr} \cdot TW \cdot g \cdot v$$

where P_r is power to overcome rolling resistance, C_{rr} is coefficient of rolling resistance for the tire used by the racer, reported to be ~0.0026 in independent testing (Bierman, 2024).

The average power output for a climb was computed as the sum of P_v , P_a and P_r assuming a transmission efficiency of 98%, as previously described to be relevant for elite male cyclists (Barnaby et al., 2021). To validate the model for power output, the same procedure was applied to a rider on stage 15 2024 (Derek Gee, body weight 72 kg, height 189 cm) that reported power meter data on Strava (Tech, 2025). As average power meter data for prolonged efforts appear to be a reliable representation of the power output (Salas-Montoro et al., 2025)

To calculate the $\dot{V}O_2$ corresponding to the physical effort, average power was converted to kilo calories per minute. Additionally, a gross efficiency for the rider was assumed to be 23%, on par or somewhat higher than the highest values reported in a previous multi Tour de France winner and notably higher than reported in other well trained cyclists (Coyle, 2005; Sidossis et al., 1992). This is considered as a reasonable estimate given the consistent high performance on the world stage for the rider examined in this brief report. Assuming a high RQ for these performances 5.189 kcal per Liter O_2 was used to calculate the oxygen consumption for the energy expenditure of the climb (Péronnet & Massicotte, 1991). A spreadsheet calculator of the methods described has been made available as supplementary material in an Excel file (https://doi.org/10.6084/m9.figshare.30546092.v1).

3 Results

Rider anthropometrics were height 176 cm and body weight 66 kg. The bike weight was set at 7.2 kg.

Elevation gain of the segments used were 1217, 1132, 1146, 1033, 564, 1569 meters, with corresponding ascent times of 38:38, 37:49, 39:04, 33:27, 17:56 and 53:47 for Plateau de Beille, Isola 2000 and Col de la Couillole, Hautacam, Peyragudes and Mont Ventoux respectively (Strava, 2025a, 2025b, 2025c, 2025d, 2025e, 2025f). The validation computation against the rider that reported power data on Strava showed a 96% model fit. Thus 4% was added to the average power output.

The mean power output during the six climbs was 442 ± 15 W (standard deviation), with a mean oxygen consumption of 80 ± 3 ml $\cdot kg^{-1}\cdot min^{-1}$ during the mean climb time of 40 ± 13 minutes. Average power outputs of the climbs and the $\dot{V}O_2$ corresponding to the average efforts of the climbs are reported in Table 1.

Table 1. Power output and oxygen consumption of climbing performance.

Climb	W	$W\cdot kg^{-1}$	$L\cdot min^{-1}$	$ml\cdot kg^{-1}\cdot min^{-1}$
Plateau de Beille	453	6.9	5.434	82
Isola 2000	446	6.8	5.356	81
Col de la Couillole	428	6.5	5.144	78
Hautacam	441	6.7	5.305	80
Peyragudes	462	7	5.550	84
Mont Ventoux	421	6.4	5.053	77

4 Discussion

The results of this theoretical computation reveal the underlying efforts and the capacity to sustain high oxygen consumption for extended periods of time needed to perform the exceptional feats of endurance performance delivered in the mountain stages by this and last year's Tour de France winner. Likely these values are a close estimation of what must have been exerted for the climb of Plateau de Beille, Isola 2000, Col de la Couillole, Hautacam, Peyragudes and Mont Ventoux. Although, positioning of the rider on the bike during climbing is possibly somewhat less aerodynamical than assumed in this computation it is likely of minimal influence. Taken together the results underscores the high level of performance necessary for these exceptional climbing performances. Highlighted by the record times and the amount they crushed previous records by. In fact, on the Plateau de Beille climb all the three first riders crossing the finish line on the stage in 2024 were faster than the long-standing record set by Marco Pantani in 1998.

Importantly, the values reported are average for the whole length of the climbs from start to finish. Knowing that Jonas Vingegaard attacked in perhaps the most challenging part of the climb of Plateau de Beille, and that Tadej Pogačar followed and counterattacked, the numbers of those parts of the climb was likely significantly higher than the reported average. However, the average may still give some valuable information as given the power output and the time it was sustained, the performance is likely close to the critical power (CP) of the athlete. Indeed, a critical power of ~417 W has previously been reported to be successful as a male Grand Tour rider, and ~410 W in elite U23 riders (Lamberts et al., 2024; Leo et al., 2022). Thus, the somewhat higher estimates to complete these record-breaking climbs seem reasonable.

Knowing an estimate of CP it is possible to estimate the $\dot{V}O_2max$ given that CP in elite cyclists likely occur at a high level of $\dot{V}O_2max$, approximately 85-90 % of $\dot{V}O_2max$ (Jones et al., 2019). Disregarding the $\dot{V}O_2$ value obtained for the mountain time trial in 2025, due to its somewhat shorter time, likely causing a significant portion of the effort to be above CP. The values obtained for Plateau de Beille in 2024 would indicate that the $\dot{V}O_2max$ during this race was in the range of ~ 91 – 96 ml $\cdot kg^{-1}\cdot min^{-1}$ for this rider, likely in the higher end of the spectrum given that the preceding part of the stage and previous race days may have lowered his CP slightly compared to optimal conditions (Clark et al., 2018). Additionally, the previous endurance efforts may have slightly reduced the gross efficiency of the rider, making the effort more costly in $\dot{V}O_2$, which would indicate higher values of $\dot{V}O_2max$ (Hopker et al., 2017). This would speak to utilizing heart rate, which is a direct physiological response, as an indicator of excretion rather than the raw power numbers corresponding to laboratory tested thresholds alone, as the rider has also advocated himself (Attia, 2024).

$\dot{V}O_2max$ values in the high 90's for this rider is supported by his performance surpassing that of previous multi Tour de France winners with reported laboratory measured $\dot{V}O_2max$ of ~81 and 84 ml $\cdot kg^{-1}\cdot min^{-1}$ (Bell et al., 2017; Coyle, 2005). Notably, $\dot{V}O_2max$ values in the high 90s have been previously reported for a cyclist during laboratory-measured, indicating that these values are attainable for the elite of human physiology (Rønnestad et al., 2019).

5 Practical Applications

This analysis provides coaches, scientists, and athletes with benchmark estimates of the power output and oxygen uptake required to sustain record-breaking climbing performances in Grand Tour cycling. While based on modeled data and public performance metrics, the findings offer valuable insight into the physiological demands of elite climbing on road bikes, which can inform training targets, pacing strategies, and athlete profiling. The main limiting factor of the study is that theoretical estimations remain estimations even though the science behind them is well studied. Indeed, factors such as wind conditions and drafting are relevant, and may play a crucial part when competing for victory at the elite level, where marginal gains may separate success and failure. In steep climbs, and at speeds as examined in this brief report, drafting may reduce power output by ~7% in laboratory settings (van Druenen & Blocken, 2021). However, the conditions on the road in a race are more complex and this factor likely represents a far lower effect over the average of the included climbs. Furthermore, one of the climbs examined was an individual time trial where drafting was not possible.

6 Conclusions

Both the power output and the oxygen consumption produced to display these feats of athletic performance are impressive. The analysis highlights some of the key factors that likely must be present for success at the highest level of cycling competition. The efforts to attain such peak physiological performance are extreme, and exercise physiologists, coaches and fans of the sport should recognize the extreme underlying physiology that results in the excitement and entertainment of the Tour de France. Enjoy next year's race, which has been revealed to include several interesting climbs, including the Col du Galibier as the highest point (2642 m) and back-to-back finishes at Alpe d'Huez, and let's hope to see more feats pushing the limits of human physiological performance in the 2026 Tour de France.

Supplementary Materials: A spreadsheet calculator of the methods described has been made available as supplementary material in an Excel file (https://doi.org/10.6084/m9.figshare.30546092.v1).

Funding: This research received no external funding.

Acknowledgments: In this section you can acknowledge any support given which is not covered by the author contribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments).

Conflicts of Interest: The authors declare no conflict of interest.

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