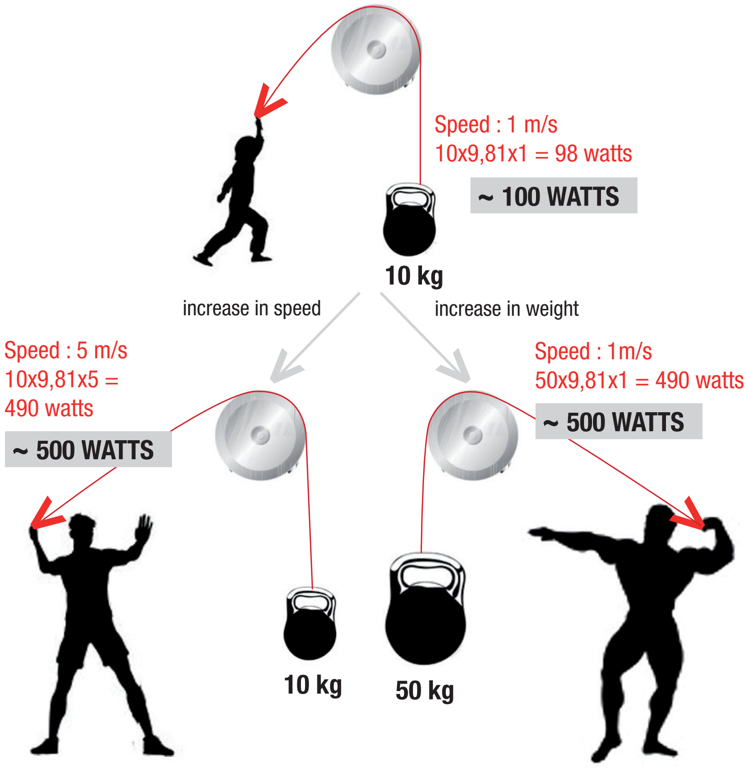
What's a watt ?

Example: a person lifts a weight using a rope and pulley as in the opposite illustration.



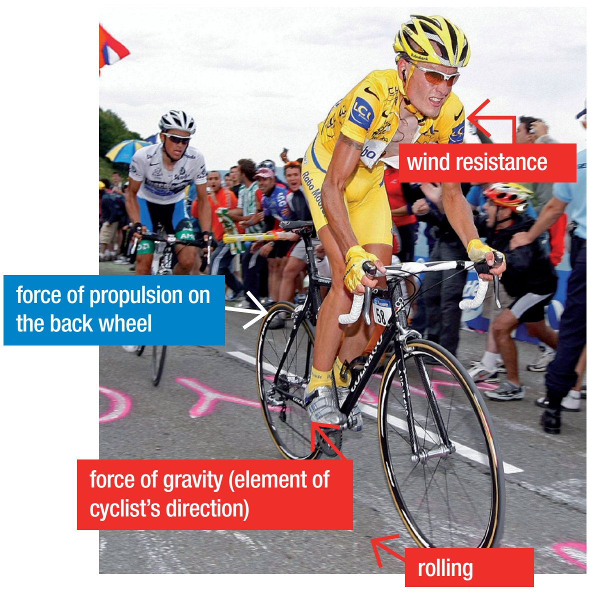
Power is the product of force (weight load = mg, with m as the load's mass and g = 9.81 m/s2) and speed. To generate 100 watts, a person would have to lift a weight of approximately 10 kg at a speed of 1 m/s. A child or an elderly person could accomplish this.

To generate more power, a person must either increase their speed or the weight load (and thus the force deployed on the rope) or both. Hence, a person would generate 500 watts if they lifted 50 kg at a speed of 1 m/s or 10 kg at a speed of 5 m/s.

A person with great force or speed could accomplish this. Power represents a person's effectiveness. By generating 100 watts, it will take them 10 seconds to lift a weight of 10 kg to a height of 10 m. By generating 500 watts, it will require 5 times less time to accomplish the same task. One must also factor duration when discussing power. The human body cannot exert itself indefinitely. It tires. Many people can generate 100 watts for 30 minutes, whereas only a few high-level athletes can generate 500 watts over the same period of time.

Rider and Grade

The cyclist's effort is more complex to model than the previous example.



A cyclist must exert propulsive force on the back wheel in order to overcome the forces that resist his forward movement.

Wind resistance depends primarily on the rider's position and the rider's relative speed squared in terms of the wind. It is low in windless climbs at 20 km/h and significant on flat terrain at 50 km/h.

Gravity pulls the cyclist downward. It is absent on flat terrain. The greater the grade of the slope, the more the cyclist will be subjected to its pull.

Rotation resistance depends on the cyclist's mass, speed, the quality of his bicycle, the surface, and his tires. There are few vertical movements, with few obstacles to overcome, unlike in mountain biking.

As he accelerates, the cyclist must also overcome inertia. When speed is constant, it equals zero. At a constant speed, force exerted by the rider on his pedals is equal to the sum of wind resistance, gravity (a component of forward movement) and rotation resistance. Another force may help the cyclist advance. This is the phenomenon known as drafting, usually occurring when behind another rider or in the peloton. Energy savings can exceed 30% inside a large peloton riding at more than 40 km/h (ref 5, Bicycling Science). In a translation system, power is the product of force and speed provided the force of propulsion is in the same direction as speed. Once all forces have been calculated, it is necessary only to multiply by speed to obtain power.

The SRM is the standard in power sensors. It measures power at the pedal level. The bicycle's output is meant to be 97.5% (transmission effectiveness, ref 1). Hence, one must add 2.5% to the model's estimated power at the back wheel in order to compare it with the pedal sensor. Based on the results on http://www.friction-facts.com/, the quality and cleanliness of the chain may also impact transmission output.

For measures of power with a sensor and related training, see Fred Grappe's book (ref 7).

The Wind Factor

Weather predictions indicate average wind speed at a height of 10 m. The wind gradient indicates wind speed based on the height of measurement, flow stability, and the ground (open space with no vegetation, city, or forest). Weather predictions tell us about average wind speed at a height of 10 m. When calculating power, we limit ourselves to measures of force in terrestrial Beauforts less than or equal to 2 (speed of 10 km/h). If the air flow is stable and non-turbulent, wind speed at rider level will not exceed 7 km/h in open spaces, 6 km/h in residential areas, and 5 km/h in forests (ref. 4, AFNOR norm and webmet.com).

Drafting

Drafting has taken on even greater importance in col climbs in the last few years. Differences in rider potential are less significant than previously. The Tour favorites peloton is now bigger than ever just before the last climb. Furthermore, a majority of riders are now equipped with power sensors. They can instantly see watts saved during a climb. According to a 2013 study (ref 3, CFD simulations of the aerodynamic drag of two drafting cyclists), wind resistance is reduced 25% at 54 km/h for a rider drafting at 10 cm.
We withheld 30% of power to overcome wind resistance in the case of a large-size peloton riding at 25 km/h, or approximately ten watts. This correction, around 2% in relative value, was for example applied to the La Toussuire climb in the 2012 Tour de France.

The 78 or 80 kg with cycle standard

The “78 kg with cycle” power standard represents an imaginary rider at the heart of the race. He weighs 78 kg, cycle and equipment included. He serves as a reference in col climbs and when tracking the evolution of performances over time. Only end-of-stage cols are compared (rider mass can decrease slightly after hours of riding). With regards to the three 80’s winners, an “80 kg cycle included” standard is used. In addition, their cycle output is decreased 5%.

Sample Calculation

Chris Horner’s Mende climb during the 2010 Tour de France

Body mass	63.5 kg
Bike and equipment mass	71.5 kg
Scx	0.35
Rolling coefficient	0.004
Average speed	18.42 km/h
Average percentage	10.26
Air density at 850 m	1.06
Bike output	97.5 %

	Détails du calcul	% total
Pair	1.06/2 x 0.35x (18.42/3.6)^3	6.00%
Protation	0.004x 9.81x 71.5x (18.42/3.6)	3.4 %
Pgravity	71.5x 9.81x (18.42/3.6) x 10.26/100	88.00%
Ptotal	(P air + P rotation + P gravity)	418 WATTS

80’s cycles: +2 kg and -5% output

2000’s cycles: 78 kg thoroughbred

The weight/power and watts/kg relationship

The watts/kg relationship is commonly used in cycling by trainers and riders in order to evaluate col climb potential. In terms of a single rider, the greater his watts/kg ratio, the faster he will climb cols, especially those with higher grades, and on which gravity is a significant factor.

Furthermore, it is directly tied to maximum specific oxygen consumption (in ml/min/kg) via energy output. Hence, we can draw parallels in terms of physiological limits.

The problem comes when we try to compare riders and their on-the-road performances. Two riders with the same watts/kg ratio but with relatively different body masses will not be able to climb at the same speed. For example, Pantani (56 kg) and Indurain (80 kg).

To climb l’Alpe d’Huez in 40 minutes, Pantani must generate 6.3 watts/kg, while Indurain can settle for 5.9 watts/kg, a 9% difference.

The watts/kg ratio would be directly proportional to on-the-road performance if there were no bicycles, no friction rotation forces and no wind resistance. The “weight/power relationship” remains nevertheless valid if we compare riders with approximately the same body mass.

Connection between power standard and watts/kg

The "78 kg with cycle" standard is related to the watts/kg ratio depending on rider mass and gradient

The following table converts the 410 w 78 kg with cycle power standard into watts/kg according to grade (%) and rider body mass.

Mass (kg)/ Grade	6 %	7 %	8 %	9 %	10 %
55	6,22 W/kg	6,17 W/kg	6,14 W/kg	6,1 W/kg	6,09 W/kg
60	6,13 W/kg	6,09 W/kg	6,06 W/kg	6,03 W/kg	6,01 W/kg
65	5,91W/kg	5,91 W/kg	5,91 W/kg	5,9 W/kg	5,9 W/kg
70	5,81 W/kg	5,82 W/kg	5,83 W/kg	5,83 W/kg	5,84 W/kg
75	5,79 W/kg	5,8 W/kg	5,8 W/kg	5,8 W/kg	5,8 W/kg

If the rider standard is at 410 watts, then the watts/kg ratio will be between 5.8 and 6.2 w/kg based on the grade and rider's build. (see image below). The greater the grade, the easier it is for lighter riders to maintain a 410 w standard.

ETALON 410 WATTS

Nevertheless, this effect is especially significant for higher average grades, which are more common in the Giro and the Vuelta than on the Tour de France and for a limited number of climbs.

The 6.8 kg low-end cycle favors bigger riders

Today, nearly all professional riders use 6.8 kg cycle. This lower limit favors bigger riders as the cycle's relative mass compared to total mass is lower when one weighs 80 kg. Twenty years ago, bigger riders needed a larger frame and rode with slightly heavier cycles than "featherweight" riders.

Power calculation accuracy

In 1998, Martin (ref 1) demonstrated that it was possible to model a cyclist's power accurately. He obtained a 2% margin of error compared to a standard power sensor. Wind speed was measured using an anemometer. The study was conducted with knowledge of riders' specific characteristics (aerodynamics, mass, cycle etc). In 2004, we conducted an in-the-field confirmation with 20 riders equipped with SRM sensors, yielding a maximum margin of error of 5%. The idea then became to decrease measurement error when using the indirect method so that it might be usable in performance analysis. The emphasis was placed on taking into account weather conditions and the definition of the measurement zone. In the last few years, professional riders have published their power sensor data online. This allowed us to corroborate further. We based the 78 kg (or 80 kg) with cycle power standard calculation on a clear reference. If the estimation of real power, as in the case of Chris Horner, is within 2%, then it will be the same for the 78 kg with cycle standard.

2010 Tour : Chris Horner

The American rider, Chris Horner, of the RadioShack team, finished 10th overall at the end of the 2010 Tour. He often rode with the front pack and therefore in the same conditions as the overall leaders. In order to avoid too much mass variation, only the last cols of stages were selected, specifically, those that were climbed after 5 hours of cycling.

SRM-Model Comparison. Chris Horner 63.5 kg, Scx = 0.35, Bike 8 kg

Cols	Distance and grade	Time	SRM	MODEL	Difference
AVORIAZ	13.7 km à 6,06 %	35'36"	351 w	347 w	1,00%
MADELEINE	25.5 km à 6 %	1h09'36"	320 w	323 w	<1%
MENDE	3.1 km à 10.26 %	10'06"	422 w	418 w	<1%
AX LES THERMES	7.8 km à 8.33 %	23'43"	370 w	375 w	+1.4 %
BALES	19.3 km à 6.1 %	49'30"	342 w	358w	+ 4.6 %
TOURMALET OUEST-BAS	9.35 km à 7,16%	23'54"	372 w	409 w	9,00%
TOURMALET OUEST-HAUT	9.3 km à 7.9 %	28'36"	348 w	354 w	+1.8%

Drafting helps explain the results at Port de Balès (8 km of slight incline at the beginning of the col) while there is a double drafting and tailwind effect on the lower portion of the Tourmalet.

With the exception of these two instances, the differential is always less than 2%. The margin of error between SRM sensors and the model is thus more than acceptable on the final cols of Tour de France mountain stages.

From experience, we concluded that a 2% margin of error was possible given the following conditions:

- **speed less than 25 km/h**
- **general wind speed at maximum of 2 on Beaufort scale**
- **Grade higher than 6%**
- **ride through forest**

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Factors influencing interpretation of rider power standard on cols

> > Climbing capacity:
the Tour winner is not necessarily the best climber. For example, Wiggins in 2012, Indurain in 1994, LeMond in 1989, Roche in 1987 and Hinault in 1982.

> Early-in-the-stage energy management:
during certain Tours, the battle was fought a fair amount of time before the last col (1986, 2011). In other instances, a strong time-trial and strong overall-leading yellow jersey can settle for tailing his opponents (Hinault in 1982, Wiggins in 2012).

> Level parity:
1989 Tour with Fignon, LeMond and Delgado, 2012 Vuelta with Contador, Valverde, and Rodriguez. On each occasion, possible winners were very similar and overall rankings were particularly tight. Sometimes, as in 1999 with Armstrong, main leaders were absent. He needed only to manage the race and did not need to “crank out the watts”. In 2006, a number of favorites were banned following the “Puerto” scandal

> Average col length of each Tour:
the shorter the cols, the greater the possibility of generating greater average power on the last cols. The power level will be high especially if riders exert themselves from the beginning of the climb or in instances of climbing time trials. (See page 13). The average length of the last cols on the Tour de France is approximately 35 minutes.

> General ability of leader’s team:
if a leader is protected, like Wiggins in 2012, with a team dedicated to working for him and teammates who are sometimes better climbers, he can expend more watts at the ends of stages.

> Weather:
extreme conditions (extreme heat or rain and cold) can hurt some riders. Though where Pantani and some of his performances are concerned, there was no visible impact on his “mutant” status.

> Route:
the greater the number of mountain stages, the more climbers pay attention to their efforts. On particularly mountainous Tours, it is normally impossible to generate maximum effort at each stage.

> Beginning or end of stage:
a nominal amount of fatigue “should” appear at the end of a mountain stage after two cols and in the third week of a long Tour. Unfortunately, this is not the case for some, who seem to improve with each passing day, and for whom five hours of riding and two cols seems to serve as a warm-up before the finish.

All of these factors must be taken into account when interpreting the power watt standard generated by riders on cols.

Validation of an indirect method of estimating mechanical power in cycling

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A.VAYER : Alternativ, C.TRONCHE : FFC,
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External mechanical power (Mec-P, W) is a key parameter of cycling performance. Different methods allow its measurement (SRM, Polar S170, Power-Tap) but they remain expensive for amateur athletes. The validity of the SRM (Fuchsend, Germany) was demonstrated by comparing it to a Monark by Martin et al. 1998. The purpose of this study is to test the validity of an indirect method of measuring Mec-P.

> METHOD – Sixteen male cyclists (21.0 ± 4,0 years old; 67,8 ± 5,8 kg ; 177,8 ± 5,8 cm ; PMA = 373 ± 43 w ; 12 687 ± 5 313 km.an-1) cycling at the regional or elite level made 15 climbs from 1.3 to 6.3 km (average grade of 4.4 to 10.7%) in random order. Each cycle was equipped with SRM pedals for Mec-P readings in different conditions (alone, in groups...). Analysis segments were determined according to notable points identified on an IGN map. These also allowed measure of speed and average grades.

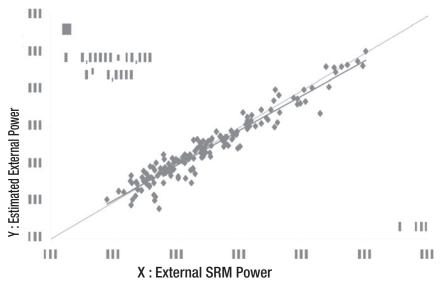

Figure 1: Correlation between SRM-P and Estimated P for all subjects and conditions.

> Calculation of Indirect Mec-P: (Di Pramp- ero 1979) MecP = 0,5.ρSCx.V3 + m.g.Cr.V + m.g.sin(ρ).V Where air density is in kg.m-3. S the frontal area in m2 ; Cx coefficient wind resistance; V the speed in m.s-1 ; m the total mass in kg ; g gravity in m.s-2 ; Cr coefficient of rolling resistance and (ρ) the slope.

> RESULTS – The strong correlation (r = 0.96 ; p<0.001) between SRM-P and Estimated-P in the majority of conditions is visible in Figure 1. Only 3 of the 15 conditions showed significant variation (strong winds). Average margin of error between the 2 methods (Figure 2) was -0.95% (I.C. 95% = -10.4 ; 8.5%) and 0.24% (I.C. = -6.1 ; 6.6%) for windless conditions. No effect of slope on average margin of error.

> DISCUSSION – This study reveals the strong impact of wind resistance. In unfavorable wind conditions, SRM-P is higher than Estimated-P, which is corroborated in published data (Olds et al. 1993). There was no improvement based on slope. This can be explained by the fact that all grades were greater than 4.4%. In the “group” condition, the confidence interval (IC) is lower because wind resistance is diminished.

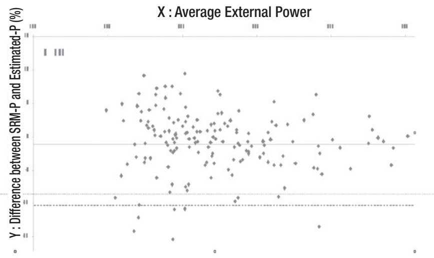

Figure 2: Average differences between SRM-P and Estimated-P for all conditions (value > 0; Estimated-P > SRM-P).

> CONCLUSION – This method appears to be of satisfactory accuracy and validity to evaluate external Mec-P in cycling, provided two conditions are met: a strong grade (>4%) and low wind resistance. This tool is therefore useful for trainers. It offers the advantage of allowing on-the-road tests at low cost. In addition, it allows rigorous analysis of the evolution in performance of professional cyclists.

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