

Determination of Maximal Aerobic Power on the field in cycling

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Abstract

In cycling, the maximal aerobic power (MAP) is an important parameter for the coaches in the training process and the monitoring of the cyclist's aerobic potential. However, there is no common procedure that would determine the MAP since it is dependent on the test protocol in laboratory and field. The purpose of this study was to propose a methodology from field data to determine both a field MAP, the time that MAP can be sustained (T_{MAP}) and an aerobic endurance index (AEI) in professional and elite cyclists. Twenty-eight cyclists trained and raced with mobile power meter devices fixed to their bikes during two consecutive seasons. The Record Power Profile (RPP) of each cyclist was determined from the maximal power output realised by the cyclists (i.e. record PO) on different durations between 1 second and 4 hours. The method of MAP determination was to define the upper limit of the aerobic metabolism from the relationship between the record PO (from 3 min to 4 h) and the logarithm of time. From this method, the average values of MAP and T_{MAP} were 456 ± 42 W (6.87 ± 0.5 W.kg⁻¹) (95%CI = 439 - 473 W) and 4.13 ± 0.7 min (95%CI = 3.84 - 4.42 min), respectively. All the AEI were ranged between -8.34 and -11.33 (mean AEI = -9.53 ± 0.7 , 95%CI = -9.24 / -9.82). The most important finding of this study is the possible determination of MAP, T_{MAP} and AEI on the field from the RPP. Compared to the elite cyclists, the professionals presented a higher MAP (+9.9%, $p < 0.05$) and shorter T_{MAP} (-13.5%, $p < 0.05$) with no difference in AEI. Several practical applications of this field method may be relevant and suitable for the coaches in the training monitoring of their cyclists.

Keywords: maximal aerobic power, aerobic endurance index, cycling, power output, record power profile, SRM powermeter.

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Introduction

In cycling, the maximal aerobic power (MAP) is a fundamental parameter in the training process. MAP is used by the coaches and scientists to assess the aerobic potential of the athletes, to determine the exercise intensities and is useful to monitor the adaptation to training. Several studies have shown the correlation between the MAP obtained during laboratory tests and cycling performance, as time trial (Balmer et al. 2000; Bentley et al. 2001; Hawley and Noakes 1992). However, there is no common procedure that would determine the MAP (Faria et al. 2005a). In the laboratory, MAP values determined from incremental tests are dependent on the protocol according to stage duration, work-load increase and type of ergometer (Faria et al. 2005a; Hopkins et al. 2001). Few studies have reported tests in real cycling conditions. Only Gonzales-Haro *et al.* and Nimmerichter *et al.* have proposed to assess MAP from field tests with an incremental protocol on velodrome and a 4 min time-trial, respectively (Gonzalez-Haro et al. 2007; Nimmerichter et al. 2010). In these laboratory and field

tests, the values of MAP are protocol-dependent and are defined as the power output at the maximal oxygen consumption ($\dot{V}O_{2max}$) rate. Thus, according to a protocol, a $\dot{V}O_{2max}$ value can be associated with different values of MAP. It automatically involves significant changes in the duration during which MAP can be sustained (T_{MAP}). Therefore, it would be interesting to define a procedure which assesses MAP in real cycling conditions avoiding the bias dependent of the proposed protocol.

In this context, the Record Power Profile (RPP) of the cyclist could be a suitable tool to determine MAP since it provides many advantages from the measurement of field PO, the monitoring of training and competition data and the inclusion of exercise durations from 1 s to 4h (Pinot and Grappe 2011b). The decrease of record PO over time shows a hyperbolic relation that can be explained by the combined actions of the various bioenergetic processes (Morton and Hodgson 1996). By using the method of Peronnet and Thibault (Peronnet and Thibault 1987, 1989; Peronnet et al. 1987; Tokmakidis et al. 1987), a preliminary study showed that the determination of an Aerobic Endurance Index (AEI) was possible from the RPP by analysing the linear decrease of the record PO between 5 min and 4 h when the duration is expressed as a function of the logarithm of time (PO-Log_e) (Pinot and Grappe 2011a). This model showed that the record PO corresponding to the duration of 5 min is certainly closer to the value of MAP. However, according to previous studies (Billat et



al. 1996; Bosquet et al. 2002; Faina et al. 1997), the upper limit of the aerobic metabolism could be situated between 3 and 6 min.

The purpose of this study was to propose a methodology taking into account PO in real cycling conditions to determine MAP, T_{MAP} and an AEI in professional and elite cyclists. We hypothesised that it should be possible to determine MAP from a deflection point located between 3 and 6 min on the PO-Log_t relationship at which the aerobic metabolism is maximal (Billat et al. 1996; Bosquet et al. 2002; Faina et al. 1997; Laursen et al. 2007).

Materials and methods

Subjects

This study was carried out in professional and elite cycling teams. A local ethic committee (FDJ Health and Medical Department) approved this experimental procedure according to international standards (Harris and Atkinson 2011). All the participants were volunteers. They were informed about the experimental procedure and the purpose of the present study, each gave his written informed consent. For the experimental procedure they carried out their usual activities (Winter and Maughan 2009). The data of 28 cyclists were studied. Their mean (+SD) age, height and body mass were 25 ± 4 years, 179 ± 6 cm and 67 ± 6 kg, respectively. Fifteen cyclists were members of professional cycling teams and covered between 25000 and 35000 km per year. They had between 65 and 90 days of competition per season (ranging from 1-day races to stage races of 3 weeks). The others ($n = 13$) were elite cyclists and ranked in the 1st category in France, with 7 of whom had raced with the U23 French Team. They covered distances ranging from 18000 to 23000 km per year. They had between 50 and 70 days of competition per season (ranging from 1-day races to stage races of 1 week). Study subjects had high performance levels and included 18 cyclists who

have raced World or European championship with their National Team, sprinters and climbers at the World-Tour level. Their average weekly training time was 18 ± 3 h.

SRM Measurements

The cyclists performed all their training and competitions over two consecutive seasons (22 months) with mobile power meters mounted on their bikes (SRM Professional Training System, Schoberer Rad Messtechnik, Jülich, Germany). They were accustomed to using SRM Powermeters. According to the manufacturers' recommendations, the slope of calibration for each SRM was verified every 3 months using a static calibration to determine the relationship between the torque (Nm) and frequency (Hz) (Woolles et al. 2005). The cyclists were informed of the importance of performing the zero offset frequency procedure before each training session and race in order to obtain accurate PO data (Abbiss et al. 2009; Gardner et al. 2004). Thus, the values of slope and zero offset

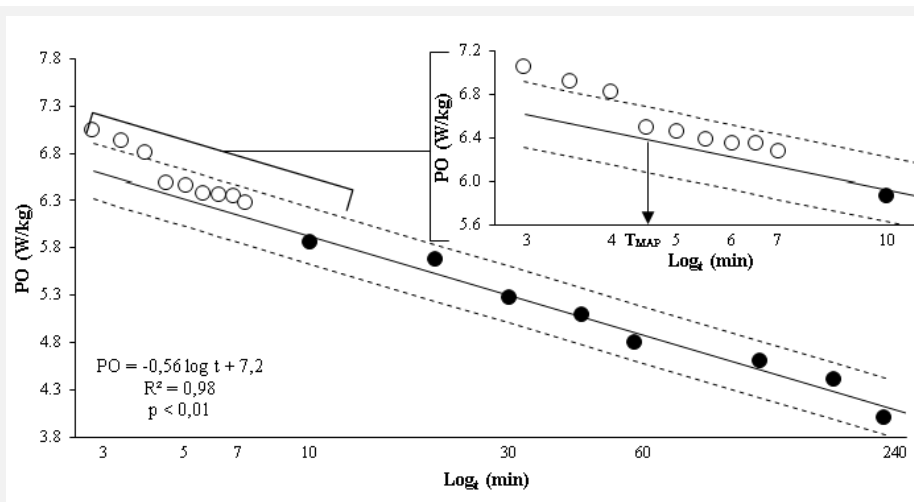


Figure 1. Methodology of determining MAP and T_{MAP} . Solid line represents the linear regression of the relationship between the record PO from 10 min to 4 h (black points) and Log_t. Dotted lines are residual 2-standard deviations of the regression. White points are record PO from 3 to 7 min, where the confidence interval is extrapolated. MAP is the first record PO inside the confidence interval (range between dotted lines). For this cyclist: MAP = 6.5 W.kg⁻¹ and T_{MAP} = 4.5 min.

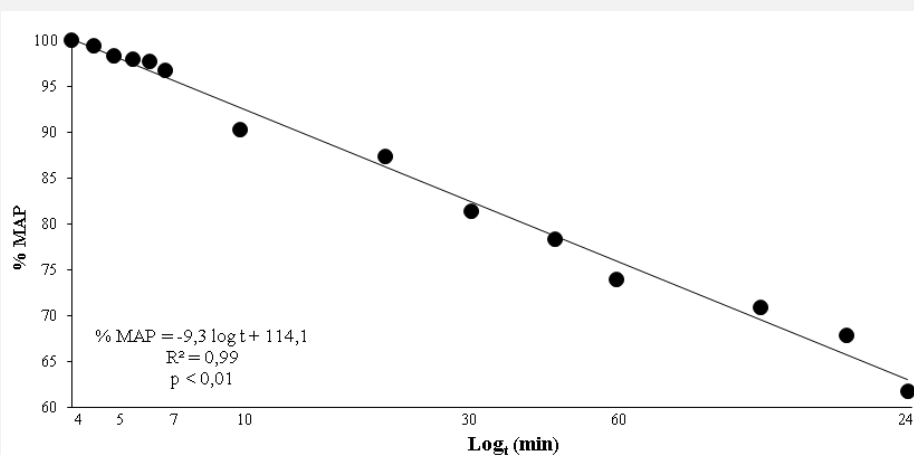


Figure 2. % MAP-Log_t relationship of the same cyclist as in Figure 1. The slope of the relationship determines the AEI (-9.3 for this cyclist)

has been verified before each analysis.

SRM Data analysis

After each training and competition, the cyclists transferred their data from the power control to their computer using the SRM Software (v6.41.04 Schoberer Rad Messtechnik, Germany). After their files were received by e-mail, the data were analysed with the use of TrainingPeaks software (WKO+, v3.0, Peakware, CO, U.S.A.). All data were analysed in order to obtain the Maximal Mean Power (MMP) for times of 1, 5 and 30 sec, and 1, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 10, 20, 30, 45, 60, 120, 180, and 240 min. Maximal values for each duration were retained to determine the various record PO.

Determination of MAP

As it is well established that T_{MAP} is lower than 10 min (Billat et al. 1996; Bosquet et al. 2002; Faina et al. 1997; Hopkins et al. 2001), according to the model of Peronnet and Thibault (Peronnet and Thibault 1987; Peronnet et al. 1987), the aerobic metabolism was modeled from RPP by a linear PO-Log_t relationship from 10 min to 4 h. The regression equation was in the form: $PO = a \ln t + b$. Residual 2-standard deviations (r_{2SD}) equations of the linear regression were calculated by the equations $PO = a \ln t + b \pm r_{2SD}$. A confidence interval was plotted by extrapolating the range between the r_{2SD} lines until 3 min from the experimental data (10 min to 4 h). This confidence interval provides a

Table 1. Average record POs for various time durations (min) for 26 cyclists. Values are Mean ± SD, and Range [minimum – maximum].

Duration	Absolute PO (W)	Absolute PO Range (W)	Normalised PO (W.kg ⁻¹)	Normalised PO Range (W.kg ⁻¹)
0.016	1339 ± 164	[1018 – 1691]	20.1 ± 1.6	[17.6 – 23.6]
0.083	1268 ± 144	[984– 1580]	19.1 ± 1.4	[16.9–21.6]
0.5	865 ± 93	[709 - 1056]	13.0 ± 1.1	[11.3 – 15.3]
1	648 ± 66	[532 - 777]	9.8 ± 0.7	[8.7 – 11.3]
3	484 ± 38	[412– 570]	7.3 ± 0.5	[6.5 – 8.5]
3.5	470 ± 37	[401– 547]	7.1 ± 0.5	[6.2 – 8.2]
4	460 ± 37	[385– 524]	6.9 ± 0.5	[6.2 – 7.8]
4.5	451 ± 37	[372– 527]	6.8 ± 0.4	[6.0 – 7.9]
5	443 ± 37	[368– 504]	6.7 ± 0.4	[5.9 – 7.5]
5.5	438 ± 37	[364– 505]	6.6 ± 0.4	[5.9 – 7.5]
6	431 ± 37	[362– 489]	6.5 ± 0.4	[5.7 – 7.4]
6.5	427 ± 37	[357– 484]	6.5 ± 0.4	[5.7 – 7.3]
7	423 ± 36	[358– 478]	6.4 ± 0.4	[5.7 – 7.3]
10	408 ± 36	[333 – 462]	6.2 ± 0.4	[5.5 – 7.0]
20	382 ± 32	[312 – 441]	5.8 ± 0.4	[5.2 – 6.6]
30	360 ± 31	[293– 410]	5.4 ± 0.4	[4.9 – 6.2]
45	343 ± 30	[289– 393]	5.2 ± 0.4	[4.4 – 5.9]
60	329 ± 28	[275– 379]	5.0 ± 0.3	[4.3 – 5.7]
120	303 ± 28	[253– 365]	4.6 ± 0.3	[4.0 – 5.2]
180	288 ± 23	[235– 338]	4.4 ± 0.2	[4.0 – 4.8]
240	272 ± 24	[221– 313]	4.1 ± 0.3	[3.4 – 4.7]

Table 2. MAP and T_{MAP} (Values are Mean ± SD, Coefficient of Variation across the group (%) [Minimum; Maximum])

	MAP (W)	MAP (W.kg ⁻¹)	T_{MAP} (min)
All cyclists	456 ± 42 (9%) [373 / 526]	6.87 ± 0.5 (7%) [6.2 / 8.0]	4.13 ± 0.7 (17%) [3.0 / 5.5]
Elite cyclists	433 ± 36 [373 / 495]	6.70 ± 0.3 [6.2 / 7.3]	4.46 ± 0.8 [3.0 / 5.5]
Professional cyclists	476 ± 38** [387 / 526]	7.02 ± 0.6* [6.2 / 8.0]	3.86 ± 0.5** [3.0 / 4.5]

*: significant difference with elite cyclists (p<0.1)
 **: significant difference with elite cyclists (p<0.05)

Table 3. Aerobic Endurance Index (AEI) (values are Mean ± SD, coefficient of variation across the group (%) and Range: Minimum/Maximum).

	Aerobic Endurance Index	Range
All cyclists	-9.53 ± 0.7 (8%)	-11.33 / -8.34
Elite cyclists	-9.33 ± 0.5 (5%)	-10.23 / -8.34
Professional cyclists	-9.71 ± 0.8 (8%)	-11.33 / -8.44

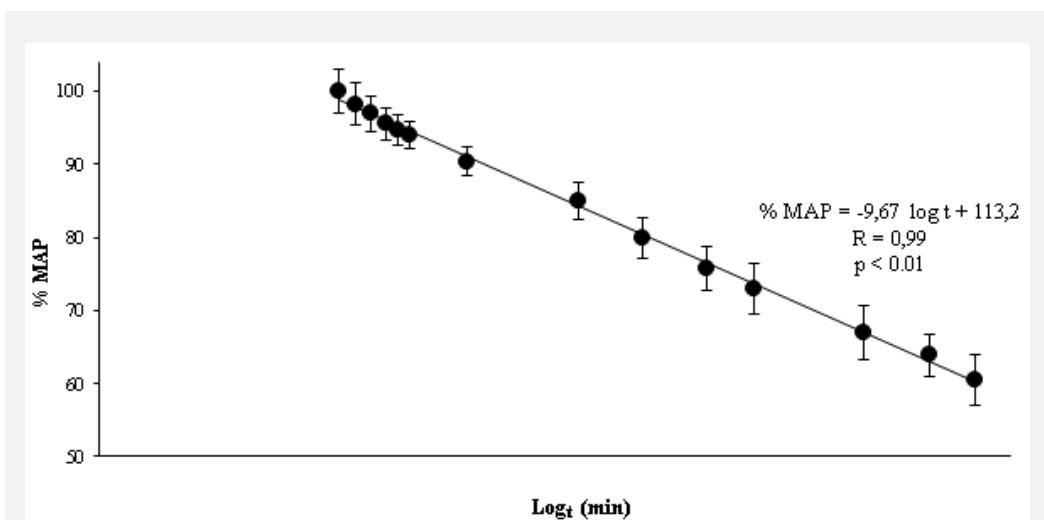


Figure 3. Average % MAP-Log_t relationship from the RPP for 26 cyclists.

window from which it is possible to determine the point at which the record PO (calculated each 30 s between 3 and 7 min) drifts upward and leaves the r_{2SD} area to show the predominance of the anaerobic metabolism. Thus, MAP has been defined as the first record PO included in the confidence interval and T_{MAP} as the sustained time equivalent at MAP. The methodology is depicted in Figure 1 with an example of rider's data.

Determination of Aerobic Endurance Index

After the determination of MAP for each subject, all the record PO were expressed in terms of percentage of MAP (% MAP) between T_{MAP} and 4 h according to the Log_t . The slope of this relationship (% MAP- Log_t) represents an index of the aerobic endurance capability (AEI) of the cyclist, as described for runners by Peronnet and Thibault (Peronnet et al. 1987). Figure 2 presents an example for a cyclist of the % MAP- Log_t relationship from T_{MAP} to 4 h.

Statistical analysis

Descriptive statistics were used, and all data were expressed as mean \pm standard deviation (SD). For each parameter, the 95% confidence interval (95%CI) was calculated. To describe the relationship between selected variables, Pearson zero-order correlation coefficients were computed by the least-squares method.

The normality of value distribution within categories was assessed with the Shapiro-Wilk test. Student t-tests were used to compare values between the two groups for MAP, T_{MAP} and AEI within categories.

Results

The RPP of 26 cyclists were used for the statistical analysis. The RPP of two riders were not retained because of invalid data. Table 1 presents the decrease of the average record PO for the 26 cyclists between

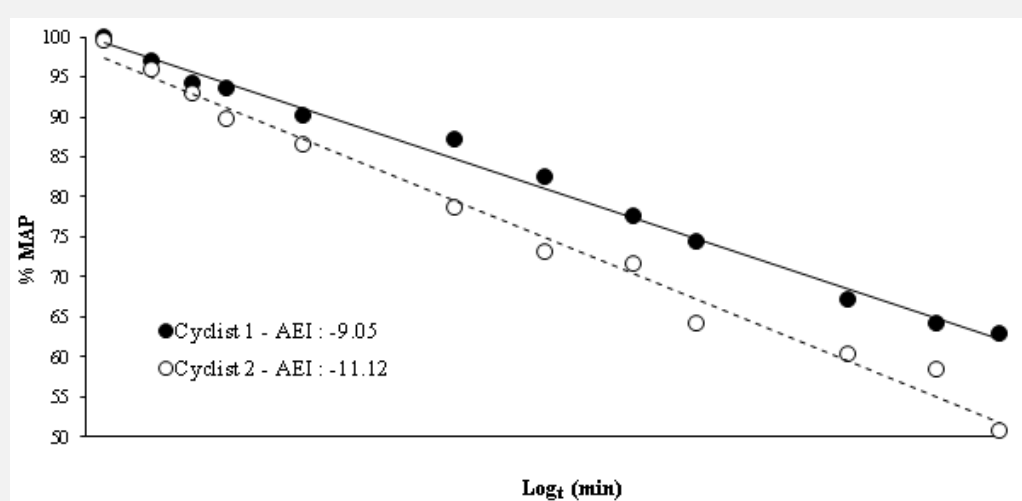


Figure 4. Comparison of aerobic endurance capabilities between two cyclists with different AEI (-9.05 and -11.12 for cyclist 1 and 2, respectively)

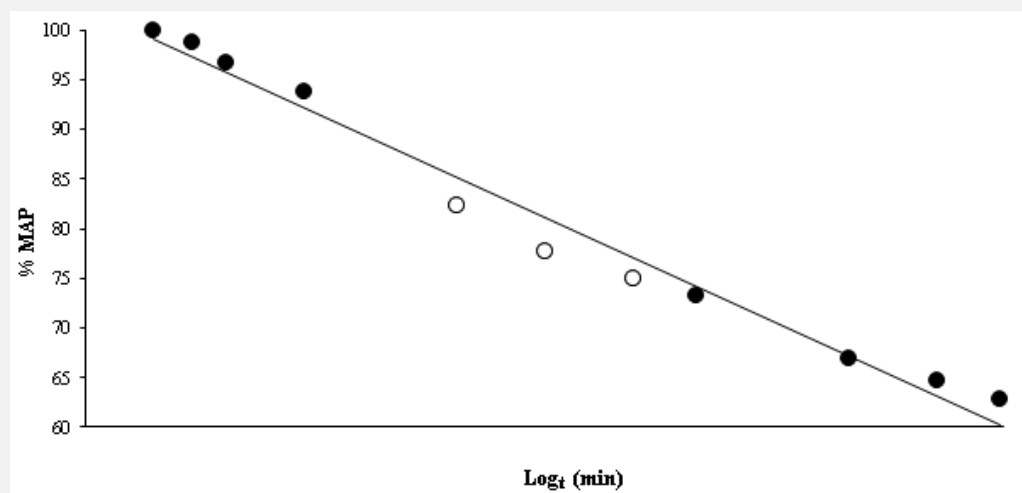


Figure 5: % MAP- Log_t relationship for a cyclist who can improve his record PO on 20, 30 and 45 min (white circles)

$1339 \pm 164 \text{ W}$ ($20.1 \pm 1.6 \text{ W.kg}^{-1}$) for 1 sec and $272 \pm 24 \text{ W}$ ($4.1 \pm 0.3 \text{ W.kg}^{-1}$) for 4 h.

Table 2 presents the average MAP and T_{MAP} for the 26 cyclists. The average values of MAP and T_{MAP} are $456 \pm 42 \text{ W}$ ($6.87 \pm 0.5 \text{ W.kg}^{-1}$) (CV = 9%, 95%CI = 439 - 473 W) and $4.13 \pm 0.7 \text{ min}$ (CV = 17%, 95%CI = 3.84 - 4.42 min), respectively. The student t-tests indicate significant differences ($p < 0.05$) between the two categories of cyclists for both MAP (in W) and T_{MAP} . Professional cyclists have a shorter T_{MAP} (-13.5%) than elite cyclists (3.86 min vs. 4.46 min). MAP of professional cyclists is higher than that of elite cyclists: 476 W vs. 433 W (+9.9%, $p < 0.05$) and 7.02 W.kg^{-1} vs. 6.70 W.kg^{-1} (+4.8%, $p < 0.1$).

The figure 3 presents the average % MAP- Log_t relationship for the 26 cyclists. The % MAPs are linearly correlated with the Log_t between T_{MAP} and 240 minutes ($R = 0.99$, $p < 0.01$). The correlation is characterised by the equation: % MAP = $-9.67 \log t + 113.2$. The mean AEI derived from the slope of the regression is equal to -9.67.

The table 3 presents the different AEI for the 26 cyclists. The AEI are ranged between -8.34 and -11.33 (mean AEI = -9.53 ± 0.7 , 95%CI = -9.24 / -9.82). The

student t-tests indicate no significant difference in AEI between the two competition levels.

Discussion

The most important finding of this study is the possible determination of MAP, T_{MAP} and AEI on the field from the RPP. Compared to the elite cyclists, the professionals presented a higher MAP (+9.9%) and shorter T_{MAP} (-13.5%) with no difference in AEI. The T_{MAP} were ranged between 3 and 6 min as it was expected according to the previous studies (Billat et al. 1996; Bosquet et al. 2002; Faina et al. 1997; Hopkins et al. 2001). Our results indicate that it appears possible to determine MAP on the field from the RPP avoiding the bias dependent of an evaluation protocol.

The use of laboratory or field test to determine MAP has been much debated (Berthon et al. 1997; Billat et al. 1996; Bosquet et al. 2002; Faina et al. 1997; Faria et al. 2005b; Hopkins et al. 2001; Laursen et al. 2007; Lucia A and J Hoyos 2004). On the field, the coaches must take into account a valid PO to establish training programmes and track the evolution of the cyclist's potential. Thus, the use of RPP appears suitable since it is obtained from a monitoring of training and competition record PO. This procedure allows to avoiding some limitations of laboratory tests to assess MAP: protocol-dependence, motivation of the athlete, ergometer... Conversely, it possesses interesting advantages, which do not exist in other tests, like specificity with real cycling conditions, accommodations of exercise durations from 1 s to 4 h and consideration of an individual time sustained at MAP. The inclusion of competition performances in the process of MAP determination seems to be essential since, as suggested by Bosquet (Bosquet et al. 2002), data gained during competitive events of differing durations represent a reliable mean of assessing aerobic endurance. Indeed, Sassi et al. (Sassi et al. 2006) explained that it was very difficult to require repeated exhaustive efforts during periods of training because highly demanding maximal tests are often unacceptable to high-level athletes, especially those close to important competitions.

The mean MAP of cyclists was equal to 456 W (6.87 $W \cdot kg^{-1}$) (95%CI = 439 - 473 W) and the corresponding mean T_{MAP} was 4.13 min (4 min and 7 s) (95%CI = 3.84 - 4.42 min) with a wide inter-individual variability (CV= 17%). The results are in accordance with previous studies which have shown similarities with $\dot{V}O_{2max}$ found by Billat et al. (3.70 \pm 1.52 min) and Faina et al. (3.75 \pm 1.57 min) with cyclists (Billat et al. 1996; Faina et al. 1997). Additionally, Nimmerichter et al. observed that the PO developed during a 4 min time trial on the field was a good predictor of the MAP measured on an incremental exercise test (Nimmerichter et al. 2010). In the same way, Allen and Coogan used a 5 min all-out test to evaluate PO corresponding at the maximal oxygen uptake (Allen and Coggan 2010). As the results show that T_{MAP} is closer to 4 min, future studies should determine 1) the interest of the 4 min field test in assessment of MAP

according to RPP and 2) if there are differences in PO between laboratory, flat and uphill time trials (Nimmerichter et al. 2010).

Significant differences in MAP and T_{MAP} were found between elite and professional cyclists. Professional cyclists had higher MAP ($p < 0.05$) (476 W / 7.02 $W \cdot kg^{-1}$ vs 433 W / 6.70 $W \cdot kg^{-1}$) than elite cyclists but shorter T_{MAP} ($p < 0.05$) (3.86 min vs. 4.46 min). This result is in accordance with those of Billat et al. (Billat and Koralsztein 1996; Billat et al. 1994) showing that athletes with the highest maximal aerobic PO are those with the shortest time to exhaustion. Nevertheless, no significant correlation was found between MAP and T_{MAP} .

The AEI was determined in this study from the relationship between record PO, expressed according to % MAP and log time (between T_{MAP} and 4 h), by using the RPP of 26 cyclists according to the method of Pinot and Grappe (Pinot and Grappe 2011a). The regression can be expressed by the equation: % MAP = -9.67 log t + 113.2 ($r = 0.99$, $p < 0.001$), which can be considered as an expression of the mean aerobic potential of high-level cyclists.

To the best of our knowledge, no study has been conducted to assess the aerobic endurance capability from AEI in cycling with field measurements of PO according to the model of Peronnet and Thibault (Peronnet and Thibault 1987; Peronnet et al. 1987). Previous studies have determined AEI from $\dot{V}O_2$ estimated from running performances (Bosquet et al. 2002; Lacour and Flandrois 1977; Peronnet and Thibault 1987, 1989; Peronnet et al. 1987). The AEI obtained in this study from PO measurements (mean : -9.53, ranged between -8.34 and -11.3) were lower than the mean AEI (-6.40) and limit values (-4.07 and -9.96, CV=23%) determined previously from indirect % $\dot{V}O_{2max}$ in a population of 18 marathon runners (Peronnet et al. 1987). AEI reflects the capacity to limit loss of PO with increased duration of exercise. The higher the AEI is, the better the aerobic endurance capability is (Peronnet and Thibault 1987; Peronnet et al. 1987). The use of RPP improves assessment of AEI because it is computed from several record PO, contrary to the method of Peronnet and Thibault which uses only two performances. In addition, the determination of AEI in this study was based on direct field measurements of PO, whereas the runners' AEI was determined with a somewhat imprecise indirect method from estimates of $\dot{V}O_2$ using running speeds. The differences in AEI between cycling and running may be due to changes of both muscle contractions (concentric vs. plyometric in running) and measuring methods. These findings suggest that the method for assessing aerobic endurance capability from AEI in elite cyclists appears valid, since it remains true to its definition (i.e., the ability to sustain a high % MAP (or $\dot{V}O_{2max}$) for a long period of time) (Bosquet et al. 2002; Lacour and Flandrois 1977; Peronnet et al. 1987; Tokmakidis et al. 1987).

No significant difference in AEI was observed between elite (-9.33) and professional cyclists (-9.71). The

similarity of AEI between these two categories of cyclists could be explained by the fact that the majority of elite cyclists belonged to the U23 national team and had the potential to become professionals. Thus, their endurance training was close enough to the professional cyclists. The population studied included only high-level cyclists. Therefore, it would be interesting in a future study to assess this capability in novice cyclists, amateurs, track riders and mountain bikers in order to track aerobic endurance of different competition levels.

Practical applications

In cycling, MAP is a central parameter in the training process and in the monitoring of the physical potential. As there is no existing a reference protocol to assess MAP, the proposed field method in this study offers many advantages previously mentioned. Since the PO developed by a cyclist is measured directly on the bicycle during training and competition, it has become widely admitted that the field data collecting is of great value. Thus, the values of MAP obtained from a valid RPP could allow the coach to optimize the prescription of the exercise training loads in power-based training.

The assessment of endurance aerobic capability with AEI also appears to be a relevant process to evaluate the aerobic potential of cyclists. As mentioned by Bosquet (Bosquet et al. 2002), the major advantage of AEI is its accessibility, since this index can be estimated easily from field performance data ranging between 4 min to 4 h. It remains a convenient tool for modelling aerobic endurance.

The % MAP-Log_t relationship allows a coach to track the cyclist fitness with a different point of view 1) to compare aerobic endurance capability of cyclists with different levels of MAP (Figure 4) and 2) to draw the virtual % MAP-Log_t relationship for a cyclist who never reached his maximum physical potential over various durations (Figure 5). Thus, it becomes possible to estimate the PO potentially achievable by a cyclist from the % MAP-Log_t relationship and, therefore, a more accurate AEI.

More generally, the exercise intensity zones are determined for the power-based training process after the assessment of MAP with a traditional incremental peak-power output test in laboratory or a field test (Gonzalez-Haro et al. 2007; Nimmerichter et al. 2010). The % MAP-Log_t relationship provide an additional method to determine the different exercise intensity zones. As the durations required to draw this relationship are ranged from 1 s to 240 min, aerobic and anaerobic areas (Pinot and Grappe 2011b) can be determined from the % MAP according to the results of this study: Zone 1 (low exercise intensity, below 60% MAP), Zone 2 (moderate exercise intensity, from 60 to 75% MAP), Zone 3 (heavy exercise intensity, from 75 to 85% MAP), Zone 4 (severe exercise intensity - low end, from 85 to 100% MAP), Zone 5 (severe exercise intensity - high end, from 100 to 190% MAP) and

Zone 6 (force-velocity: from 190% to 320% MAP).

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Conflict of interest statement

No funding was received for this work (from the National Institutes of Health, the Wellcome Trust, The Howard Hughes Medical Institute, or any others). The authors declare that there are no conflicts of interest. The results of this study do not benefit to any companies or manufacturers.

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