

CHAPITRE 4 : Détermination d'une méthode d'évaluation de la PMA et de l'endurance aérobie en cyclisme sur le terrain

Les résultats de ce travail ont fait l'objet d'un article publié dans la revue *Journal of Science and Cycling* : « Determination of Maximal Aerobic Power on the field in cycling » (Pinot J et Grappe, 2014)

Résumé détaillé

Determination of Maximal Aerobic Power on the field in cycling

Pinot J et Grappe F

Etat de l'art : La PMA est une variable particulièrement intéressante à prendre en considération dans le processus d'entraînement en cyclisme. Plusieurs études ont montré la corrélation significative qui existe entre la PMA évaluée en laboratoire et la performance en cyclisme en CLM (Hawley et Noakes, 1992 ; Balmer *et al.*, 2000 ; Bentley *et al.*, 2001). Cependant, la PMA étant protocole-dépendante, il n'existe aucun protocole de référence pour la déterminer (Faria *et al.*, 2005). Seules deux études ont rapportés des tests d'évaluation sur le terrain pour l'évaluer, l'une à partir d'un test incrémental sur vélodrome (Gonzalez-Haro *et al.*, 2007) et l'autre à partir d'un test maximal sur le terrain de 4 min (Nimmerichter *et al.*, 2010). Les différents protocoles induisent des variations significatives du temps de maintien (T_{PMA}) (Bosquet *et al.*, 2002). Dans ce contexte, l'utilisation du PPR pourrait être un moyen approprié pour déterminer la PMA puisqu'il apporte plusieurs avantages : mesure de $P_{méca}$ sur le terrain, monitoring de l'entraînement et des compétitions ou encore inclusion de durées d'efforts maximales comprises entre 1 sec et 4h (Pinot J. et Grappe, 2011). En effet, en se basant sur le modèle de Peronnet et Thibault (Peronnet et Thibault, 1984 ; Peronnet *et al.*, 1987 ; Tokmakidis *et al.*, 1987), il est théoriquement possible d'évaluer le potentiel aérobie du cycliste à partir de la régression linéaire entre les $P_{méca}$ records et le logarithme du temps (\log_t). L'une des limites du modèle de Peronnet et Thibault réside dans le fait que T_{MAP} est

considéré constant (7 min) pour tous les athlètes alors qu'en cyclisme, il se situerait entre 3 et 6 min ((Billat *et al.*, 1996 ; Faina *et al.*, 1997 ; Bosquet *et al.*, 2002)).

Objectif : L'objectif de cette étude était de proposer une méthodologie d'évaluation de la PMA, de T_{PMA} et d'un indice de la capacité d'endurance aérobie (index d'endurance aérobie) chez des cyclistes à partir du PPR. Nous avons fait l'hypothèse qu'il devait être possible de déterminer pour chaque cycliste la PMA à partir d'un point de déflection situé entre 3 et 6 min dans la relation $P_{méca}$ record – \log_t , ce point correspondant à la puissance maximale du métabolisme aérobie.

Méthodes : 28 cyclistes de haut niveau (15 professionnels et 13 élites) ont réalisé l'ensemble des entraînements et des compétitions pendant deux années avec un capteur de puissance SRM. Le PPR de chaque cycliste a été établi à partir des $P_{méca}$ records sur 1, 5 et 30 sec, 1, 3, 3,5, 4, 4,5, 5, 5,5, 6, 6,5, 7, 10, 20, 30, 45 et 60 min, 2, 3 et 4 h. Considérant que T_{MAP} était inférieur à 10 min et sur la base du modèle de Peronnet et Thibault, le métabolisme aérobie de chaque cycliste a été modélisé à partir du PPR avec la relation linéaire qui existe entre les $P_{méca}$ records et le \log_t entre 10 min et 4 h. Les régressions linéaires équivalentes à ± 2 écarts-types résiduels ont été calculées pour délimiter un intervalle de confiance encadrant la régression linéaire $P_{méca}$ record - \log_t . Cette dernière était extrapolée autour des $P_{méca}$ records comprises entre 3 et 10 min pour déterminer le point d'inflexion correspondant à la puissance maximale du métabolisme aérobie (PMA). La PMA était définie à partir de la première $P_{méca}$ record située à l'intérieur de l'intervalle de confiance et T_{PMA} avec la durée correspondante à cette dernière (figure 28).

Un index de la capacité d'endurance aérobie de l'athlète a été déterminé en exprimant les $P_{méca}$ records en pourcentage de la PMA (%_{PMA}) entre T_{MAP} et 4h en fonction de \log_t . La pente de la relation %_{PMA} – \log_t correspondait à l'indice d'endurance selon la méthodologie utilisée par Peronnet et Thibaut en course à pied (figure 29).

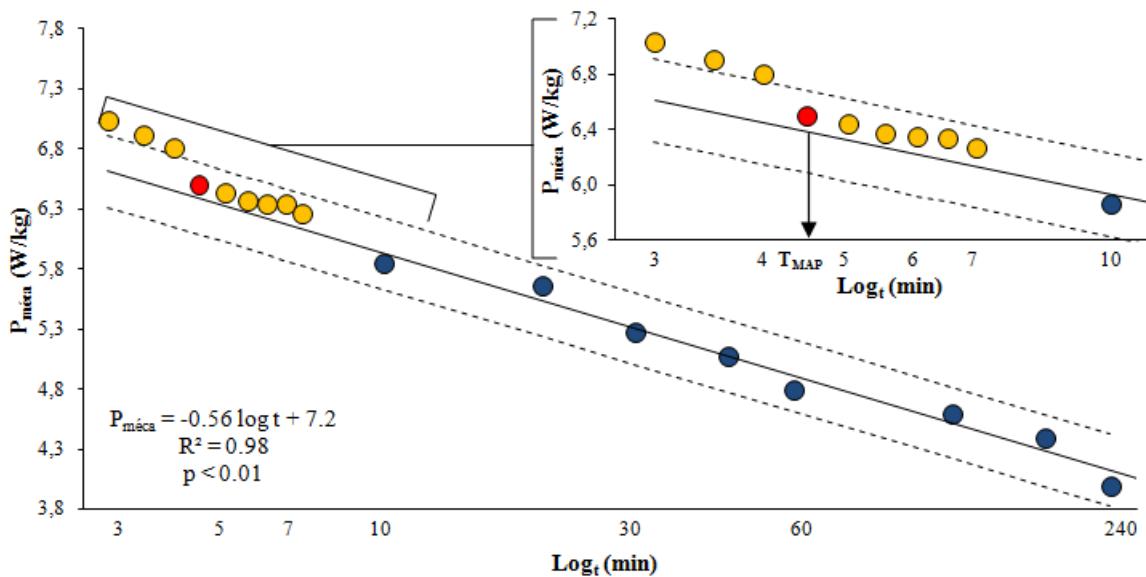


Figure 28 Méthodologie de détermination de PMA et T_{PMA} . La ligne continue représente la régression linéaire de la relation $P_{\text{méca}}$ record – \log_t entre 10 min et 4 h (bleu). Les lignes pointillées représentent les extrémités de l'intervalle de confiance équivalentes à 2 écarts-types résiduels à la régression. L'intervalle de confiance est extrapolé autour des $P_{\text{méca}}$ records entre 3 et 7 min (jaune). PMA est la première $P_{\text{méca}}$ record à l'intérieur de l'intervalle de confiance (rouge). Pour ce cycliste : PMA = 6,5 W/kg et $T_{PMA} = 4,5$ min.

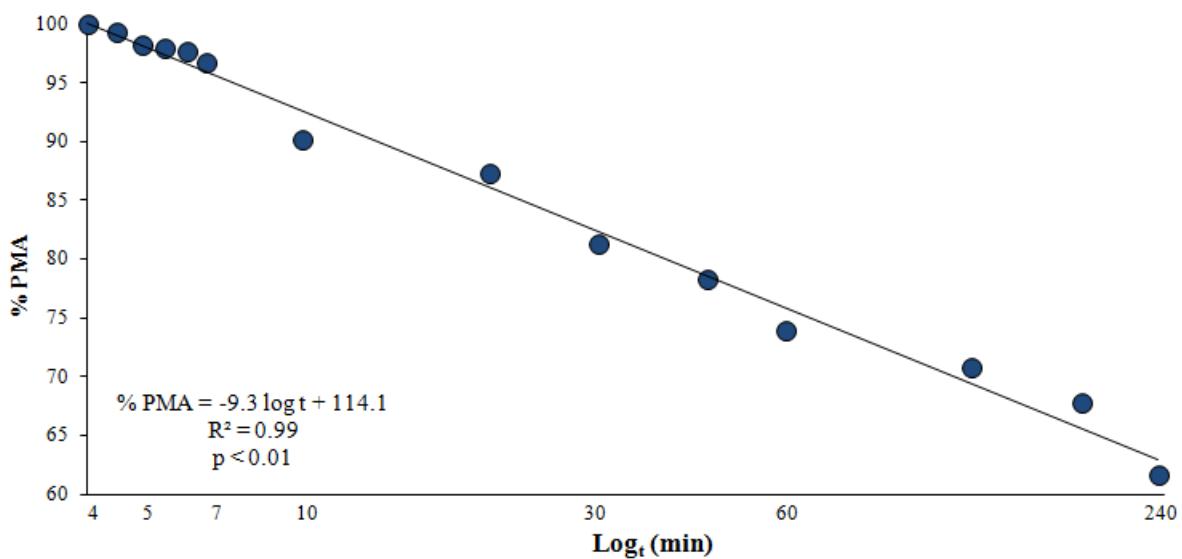


Figure 29 Relation % PMA – \log_t du même cycliste que dans la figure 28. La pente de cette relation détermine l'indice d'endurance aérobie (-9,3 pour ce cycliste)

Résultats : A partir de cette méthodologie, les valeurs de PMA et T_{PMA} moyens sur l'ensemble du groupe étaient respectivement de 456 ± 42 W ($6,87 \pm 0,5$ W) et de $4,13 \pm 0,7$ min. Les cyclistes professionnels avaient une PMA significativement supérieure à celle des élites : 476 W vs. 433 W. Par contre, T_{PMA} était significativement supérieur chez les cyclistes élites : 4,46 min vs. 3,86 min. L'indice d'endurance aérobie moyen des cyclistes était de -9,53, et il était compris entre -8,34 et -11,33. Il n'existe pas de différence significative entre l'indice d'endurance aérobie des professionnels et celui des élites.

Discussion : Cette méthodologie de détermination de la PMA et de T_{PMA} possèdent plusieurs avantages par rapport aux protocoles classiques généralement réalisés en laboratoire : 1) spécificité de la mesure de $P_{méca}$ en conditions réelles sur le terrain, 2) motivation de l'athlète supérieure, 3) prise en considération d'efforts maximaux entre 1 sec et 4h, 4) individualisation du temps de maintien à PMA et 5) affranchissement de l'utilisation d'un ergomètre.

La valeur moyenne de T_{PMA} obtenue chez le groupe de cyclistes (4,13 min) est en accord avec les études précédentes qui ont évalué le temps de maintien à $\dot{V}O_{2\max}$ (Billat *et al.*, 1996 ; Faina *et al.*, 1997). De plus, Nimmerichter *et al.* (2010) avait montré que la $P_{méca}$ mesurée lors d'un test maximal de 4 min sur le terrain était un bon prédicteur de la PMA. Le fait que les cyclistes professionnels possèdent une PMA supérieure mais un T_{PMA} inférieur aux cyclistes élites est en lien avec les études de Billat *et al.* qui ont observé que les athlètes avec les $\dot{V}O_{2\max}$ les plus élevées étaient ceux qui avaient un temps de maintien le plus court (Billat *et al.*, 1994 ; Billat et Koralsztein, 1996).

Cette étude est également la première à évaluer un indice de la capacité d'endurance aérobie en cyclisme à partir de la mesure de la $P_{méca}$ sur la base de la méthodologie utilisée par Peronnet et Thibault (Peronnet et Thibault, 1984 ; Peronnet *et al.*, 1987 ; Tokmakidis *et al.*, 1987). L'indice d'endurance aérobie reflète la capacité à limiter la perte de $P_{méca}$ avec l'augmentation de la durée de l'effort. Plus l'indice est élevé, meilleure est la capacité d'endurance aérobie de l'athlète. L'utilisation du PPR apporte davantage de fiabilité dans la méthodologie étant donné que Peronnet et Thibault déterminaient leur indice sur la base d'estimations indirectes de la $\dot{V}O_2$ à partir de performances réalisées en course à pied et en fixant la durée de maintien de la $\dot{V}O_{2\max}$ à 7 min pour tous les athlètes. Les résultats suggèrent que cette méthode d'évaluation de l'endurance aérobie est valide étant donné qu'elle est fidèle à sa définition c'est-à-dire à la capacité de maintenir des %PMA élevés sur de longues périodes de temps.

De nombreuses applications pratiques pour le processus d'entraînement peuvent être tirées de cette étude. En effet, la détermination d'une PMA de terrain permet d'affiner la programmation des entraînements et notamment d'améliorer le calibrage des zones d'intensité durant l'effort. La relation $\%_{MAP} - \log_t$ autorise l'entraîneur à évaluer la capacité d'endurance aérobio du cycliste et à suivre son évolution dans le temps.

Conclusion : Le résultat principal de cette étude montre qu'il est possible de déterminer PMA, T_{PMA} et un indice d'endurance aérobio avec des mesures de $P_{méca}$ réalisées sur le terrain à partir du PPR. Il peut en découler de nombreuses applications pratiques utiles dans le suivi du processus d'entraînement en cyclisme.

RESEARCH ARTICLE

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Determination of Maximal Aerobic Power on the field in cycling

Julien Pinot^{1,2}✉ and Frederic Grappe^{1,2}**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 ($\dot{V}O_{2\max}$) rate. Thus, according to a protocol, a $\dot{V}O_{2\max}$ 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) (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) (Wooles 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

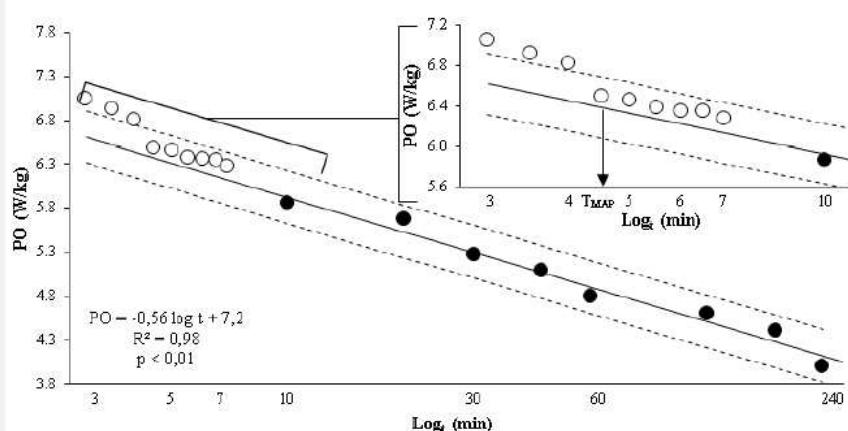


Figure 1. Methodology of determining MAP and T_{MAP}. Solid line represents the linear regression of the relationship between the record PO from 10 min to 4 h (black points) and Log_t. Dotted lines are residual 2-standard deviations of the regression. White points are record PO from 3 to 7 min, where 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.

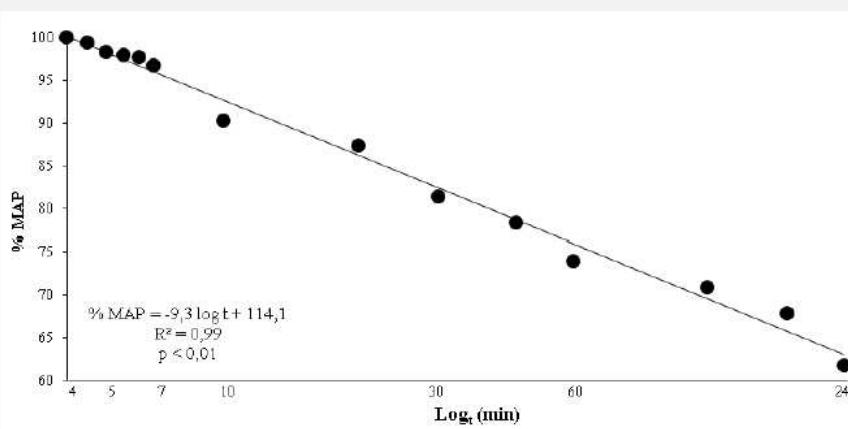


Figure 2. % MAP-Log_t relationship of the same cyclist as in Figure 1. The slope of the relationship determines the AEI (-9.3 for this cyclist)

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 \pm SD, and Range [minimum – maximum].

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

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

	MAP (W)	MAP ($W \cdot kg^{-1}$)	T_{MAP} (min)
All cyclists	456 \pm 42 (9%)	6.87 \pm 0.5 (7%)	4.13 \pm 0.7 (17%)
	[373 / 526]	[6.2 / 8.0]	[3.0 / 5.5]
Elite cyclists	433 \pm 36	6.70 \pm 0.3	4.46 \pm 0.8
	[373 / 495]	[6.2 / 7.3]	[3.0 / 5.5]
Professional cyclists	476 \pm 38**	7.02 \pm 0.6*	3.86 \pm 0.5**
	[387 / 526]	[6.2 / 8.0]	[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 \pm SD, coefficient of variation across the group (%) and Range: Minimum/Maximum).

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

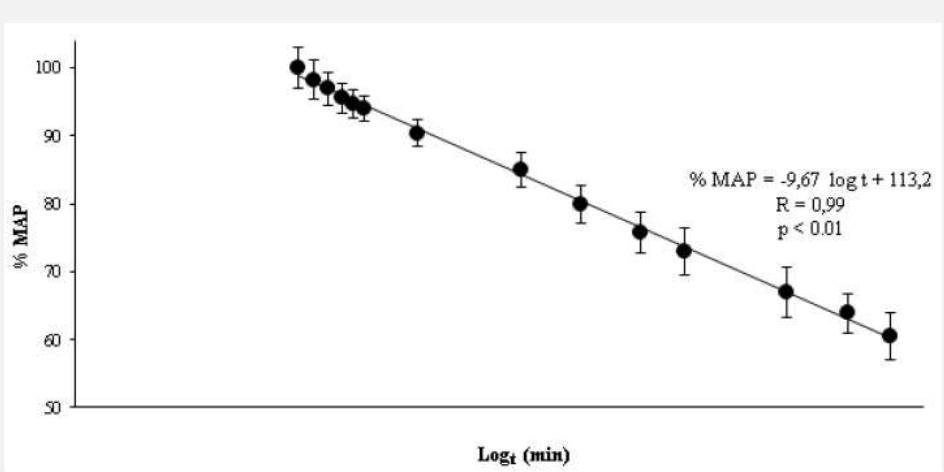


Figure 3. Average % MAP- $\log t$ relationship from the RPP for 26 cyclists.

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 1339 ± 164 W (20.1 ± 1.6 W.kg⁻¹) for 1 sec and 272 ± 24 W (4.1 ± 0.3 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 ± 42 W (6.87 ± 0.5 W.kg⁻¹) (CV = 9%, 95%CI = 439 - 473 W) and 4.13 ± 0.7 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 avoid 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.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 $\dot{V}O_{2\max}$ found by Billat et al. (3.70 ± 1.52 min) and Faina et al. (3.75 ± 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 Coggan 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.kg⁻¹ vs 433 W / 6.70 W.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 % $\dot{V}O_{2\max}$ 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' AIE 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 $\dot{V}O_{2\max}$) 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

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CHAPITRE 5 : Influence des conditions et de la nature du terrain sur la $P_{\text{méca}}$ produite lors d'un test maximal sur 4 minutes

Les résultats de ce travail ont fait l'objet d'un article soumis dans la revue *International Journal of Sport Medicine* : « Dependency of pedalling condition in 4-min time trial test on maximal aerobic power ». Il est en cours de révision avec une acceptation sous réserve de modifications.

Résumé détaillé

Dependency of pedalling condition in 4-min time trial test on maximal aerobic power

Bouillod A, Pinot J, Soenen F, Ouvrard Y et Grappe F

Etat de l'art : Nimmerichter et al. (2010) ont montré que la $P_{\text{méca}}$ mesurée lors d'un test maximal de 4 min sur le terrain était un protocole valide d'évaluation de la PMA. L'étude récente de Pinot et Grappe (2014) va dans le même sens puisqu'elle a montré que le T_{PMA} moyen d'un groupe de 28 cyclistes de haut niveau était de 4,13 min. Cependant, plusieurs études tendent à rapporter que la nature du terrain pourrait influencer le niveau de $P_{\text{méca}}$ lors d'un test maximal (Padilla et al., 2000 ; Bertucci et al., 2007 ; Vogt, Schumacher, Blum, et al., 2007 ; Vogt, Schumacher, Roecker, et al., 2007).

Objectif : L'objectif de cette étude était d'analyser l'influence des conditions de pratique (laboratoire vs. terrain plat vs. terrain en montée) sur la $P_{\text{méca}}$ déterminée lors d'un test maximal de 4 min ($P_{\text{méca-4min}}$). Dans un second temps, la concordance avec un test incrémental classique réalisée en laboratoire a été étudiée.

Méthodes : 16 cyclistes de niveau hétérogène ont réalisé 6 sessions de tests, séparés d'au moins 48 h : un test incrémental en laboratoire sur un cyclo-ergomètre SRM (30 W / 2 min), deux tests maximaux d'habituation de 4 min sur le terrain et trois tests maximaux de 4 min dans un ordre randomisé en laboratoire sur cyclo-ergomètre, sur terrain plat et en montée (8%). Les cyclistes ont réalisé les tests sur le terrain avec un capteur de puissance Powertap. Afin d'être au plus proche des conditions réelles de pratique, ils pouvaient alterner les

positions assis et danseuse lors du test en montée. Les indices perceptifs (RPE et plaisir) étaient relevés toutes les minutes pendant les 4 min des tests afin d'évaluer la charge affective (Baron *et al.*, 2011).

Résultats : La $P_{méca-4min}$ était significativement supérieure en montée ($6,0 \pm 0,5 \text{ W.kg}^{-1}$) par rapport aux conditions sur cyclo-ergomètre (+8% ; $5,5 \pm 0,6 \text{ W.kg}^{-1}$) et sur terrain plat (+11% ; $5,4 \pm 0,5 \text{ W.kg}^{-1}$). La PMA évaluée lors du test incrémental était inférieure de 4% par rapport à la $P_{méca-4min}$ sur cyclo-ergomètre, de 2% par rapport à celle sur terrain plat et de 13% par rapport à celle en montée. Les stratégies de gestion de l'effort des cyclistes étaient différentes en fonction des conditions. La gestion de l'effort était similaire dans les deux conditions de terrain avec un départ rapide puis une décroissance de la $P_{méca}$ au cours des 3 premières minutes. En revanche, sur cyclo-ergomètre, la $P_{méca}$ était beaucoup plus stable dans la durée. Concernant la charge affective, elle était significativement plus élevée sur cyclo-ergomètre comparé au terrain plat (+171%) et en montée (+169%).

Discussion : Les principaux résultats ont montré que lors d'un test maximal sur 4 min, le niveau moyen de $P_{méca}$ était dépendant des conditions (laboratoire *vs.* terrain) et du profil du terrain. En effet, la $P_{méca-4min}$ en montée était significativement supérieure de 8 et 11% à celle des tests réalisés sur cyclo-ergomètre et sur terrain plat, respectivement. Ces différences peuvent être expliquées par la nature différente des résistances à l'avancement rencontrées. En effet, la résistance principale sur terrain plat est représentée par la traînée aérodynamique (Kyle et Burke, 1984) alors qu'en montée c'est davantage la gravité qui prend le dessus. En laboratoire, le système de freinage et les caractéristiques du volant d'inertie de l'ergomètre jouent également un rôle. Toutes ces conditions induisent des variations significatives de l'inertie ramenée au pédalier (crank inertial load), qui a pour conséquence de modifier les paramètres biomécaniques du pédalage (couple moteur, cadence de pédalage, rendement brut) (Fregly *et al.*, 1996 ; Hansen *et al.*, 2002 ; Bertucci *et al.*, 2007). Au niveau de la cadence de pédalage, les résultats obtenus sont en accord avec les précédentes études puisque la cadence sur cyclo-ergomètre était supérieure à celle sur terrain plat (+11%), toutes les deux supérieures à celle sur terrain montant (+30%) (Bertucci *et al.*, 2012 ; Emanuele et Denoth, 2012).

Les conditions de pratique avaient également une influence sur la stratégie de gestion de l'effort et sur la charge affective. En effet, on retrouve une différence significative pour ces deux paramètres entre les conditions de terrain et de laboratoire. La charge affective était plus élevée lors du test en laboratoire comparé à la condition réelle de locomotion sur le terrain à

plat et en montée avec beaucoup moins de plaisir dans l'effort sur cyclo-ergomètre. En revanche, dans cette dernière condition, la stratégie de gestion de l'effort était meilleure avec de plus faibles variations de $P_{méca}$ pendant les 4 min de l'effort maximal. La stratégie de gestion de l'effort en relation avec la charge affective témoignent de la part du contrôle cérébral dans la régulation d'un effort maximal (Hettinga *et al.*, 2007 ; Baron *et al.*, 2011).

Le test maximal sur terrain plat déterminait le niveau de $P_{méca}$ le plus proche (1,9%) de la PMA mesurée en laboratoire, comme cela l'avait été précédemment montré par Nimmerichter *et al.* (2010). La $P_{méca-4min}$ en montée était significativement supérieure de 13% montrant bien les limites de la mesure en laboratoire.

D'un point de vue pratique, cette étude a montré qu'il était important de prendre en considération le profil du terrain dans le processus de programmation des séances d'entraînement et plus particulièrement dans la définition des zones d'intensités déterminées à partir de la $P_{méca}$.

Conclusion : Cette étude a montré que le profil du terrain avait une grande influence sur la mesure de $P_{méca}$ lors d'efforts maximaux. Par conséquent, il est particulièrement important de bien prendre en considération les conditions de pratique lors de la réalisation de tests d'évaluation du potentiel physique mais également de bien calibrer les zones d'intensité en fonction du terrain sur lequel vont évoluer les athlètes.

Original paper: Dependency of pedalling condition in 4-min time trial test on maximal aerobic power

Abstract

The effect of pedalling condition on power output (PO) and maximal aerobic power (MAP) was analysed in different 4-min time trials (TT4). It was hypothesised that the nature of pedalling activity leads to changes in PO altering the pacing strategy used by cyclists. Sixteen male cyclists underwent three TT4 under different conditions: cycle ergometer (CE), level ground (LG), and uphill (UP). The comparison between the CE, LG, and UP tests indicates that PO was significantly higher in UP compared with CE (+8.0 % p < 0.001) and LG (+11.0 % p < 0.001). Correlations were observed for PO with a trivial effect size between MAP and CE TT4 ($R = 0.96$, p < 0.001) and LG TT4 ($R = 0.76$, p < 0.05). The results suggest that PO under CE and LG TT4 depends on the pedalling condition and is a relevant predictor of MAP even if the mean PO was highly influenced by the pacing strategy. It seems to be important to measure the MAP by taking into account the cycling conditions, considering that coaches and scientists use this parameter to assess the aerobic potential of athletes and determine the exercise intensities useful for monitoring adaptation to training.

Key Words: Cycling, power output, field test.

Introduction

In evaluating cycling performance, Nimmerichter *et al.* [25] recently showed that the power output (PO) developed during a 4-min time trial (TT4) in the field was a valid test and a good predictor of the maximal aerobic power (MAP) measured on an incremental exercise test (25 W/min). Indeed, previous studies have shown that the time during which $\dot{V}O_{2\max}$ can be sustained (T_{MAP}) in cycling is located between 4 and 5 min [1, 6, 14, 29]. Thus, MAP determination on the field from a valid test appears to be relevant.

However, past studies have shown that the nature of terrain could play an important role on the PO during an individual time trial. Some authors have measured different POs between level ground and uphill road cycling conditions, but these comparisons were made for different durations. Indeed, Padilla *et al.* [26] investigated different types of time-trials among professional cyclists. Between a long time trial (3975 s) and an uphill time trial (4495 s), the authors reported a 4.5% (not significant) change in PO from 359 W to 376 W, respectively.

More recently, Vogt *et al.* [32, 33] investigated PO during the Tour de France and the 2005 Giro d'Italia. The maximal mean power (MMP) over a period of 240 s indicated PO increases of 3.6% and 13.4% under flat and mountain conditions during the Tour de France and the 2005 Giro d'Italia, respectively. The fact that PO was higher despite a longer duration of effort in the uphill time-trial suggests that higher PO can be produced [28] during uphill cycling. Moreover, the PO changes can be related to variations of the crank inertial load, which varies with the gear ratio and cyclist mass [16, 17, 20, 21], and these changes can influence the crank torque profile [4, 27]. Additionally, it is necessary to account for the manner in which the cyclist is able to mobilise the largest amount of metabolic energy during the maximal exercise. Indeed, in addition to the total amount of metabolic energy produced during the effort, the distribution of this energy is an important factor in performance [11, 12, 15, 31]. This ability, known as pacing strategy, is an important determinant of success in sporting competitions [23]. Therefore, it is essential to analyse this parameter during TT tests performed under different conditions. Finally, during a TT test, the cyclist must monitor not only the physiological reserves but also the affective loading (AL) to ensure that catastrophic failure of any physiological and emotional system does not occur before the finish time. Alternatively, AL may represent the part of brain control that contributes to pacing strategy regulation [2].

From these studies, it could be hypothesised that the PO level during a TT4 test could be dependent on both the pedalling condition and an athlete's pacing strategy. Thus, the value of MAP would be protocol-dependent, as demonstrated previously with different laboratory protocols [10]. Finally, it would be valuable and relevant to measure MAP under field conditions considering that in a laboratory, an ergometer does not offer the same mechanical properties as a classical race bicycle [17] and that the crank inertial load is not similar to road cycling locomotion.

This study aimed to analyse the effect of pedalling condition (laboratory *vs.* field) on the PO through different maximal TT4 tests and the agreement with MAP, as measured in an incremental exercise test in a laboratory. It was hypothesised that the PO would be dependent on the pacing strategy and nature of pedalling activity.

Methods

Subjects. Sixteen cyclists, ranging in competitiveness from the regional to the international level, volunteered to participate in the study. Their mean (SD) age, height, body mass, and

MAP were 19.8 (1.7) years, 179.1 (5.9) cm, 68.5 (6.1) kg, and 5.3 (0.6) W.kg⁻¹, respectively. The riders followed a regular training regimen and participated in races throughout the season. Prior to participating in any testing session, each subject provided written informed consent in accordance with the institutional Human Research Ethics Committee, and the study was performed in accordance with the ethical standards of the International Journal of Sports Medicine [22].

Experimental design. The study comprised four testing sessions separated by at least 48 h. During the first session, the subjects performed an incremental test to exhaustion on a cycle ergometer (CE) for determining the MAP. In the second session, the subjects performed two habituation tests on the field. Then, in the third, fourth, and fifth sessions, the subjects performed three maximal TT4 tests under different experimental conditions in a randomised order on the cycle ergometer (CE), level ground (LG), and uphill (UP) road (8.0%).

Incremental specific cycling test. The MAP was determined from the results of an incremental specific cycling test in the seated position on a SRM Indoor Trainer (Julich, Germany) equipped with clip-in pedals. The SRM system is considered valid for measuring the PO [18]. The initial workload was set at 100 W, and it was incremented by 30 W at intervals of 2 min. The choice of cadence was free. The test was performed until exhaustion, with both rate-perceived exertion (RPE) between 9 and 10 and a significant decrease in pedalling cadence. The MAP was determined as follows: when the final PO level was maintained over the duration (2 min), the MAP corresponded to the mean of this PO level. However, if the athlete could not sustain the required effort over the duration of the level, the MAP was calculated considering the mean PO of the lower and the final level: $MAP = PO_{lower level} + [(PO_{final level} - PO_{lower level}) \times Time_{final level}]$.

The PO, heart rate (HR), and cadence were recorded throughout the test, while the RPE was measured subjectively using the Borg scale [8].

TT4 Tests. The subjects performed the maximal TT4 “”tests under three different experimental conditions: CE with an SRM Indoor Trainer, and LG and UP with a mobile power meter (Powertap, Madison, USA) and a power control (Garmin 500, Olathe, USA) mounted on their bikes. The validity of Powertap system determines an accuracy between 1–2% in comparison with the SRM reference system [3]. The CE and LG TT4 tests were performed in the seated position, whereas in UP test, the athletes could choose to ride in the seated and standing positions in the climbing test under actual performance conditions.

Measurements. During the four testing sessions, the PO (W), HR (bpm), and cadence (rpm) were measured continuously at a frequency of 1 Hz. Before each testing session, standardized directions for RPE and pleasure [2] were read for each subject. Accounting for the motivation in the pacing strategy process, we determined the AL as a difference between RPE and pleasure [2].

Statistical analysis. Descriptive statistics were used, and all data were expressed as mean \pm standard deviation (SD). Statistical analysis was performed using SigmaPlot 12.0 software (Systat Inc. San Jose, USA). A Kolmogorov-Smirnov-Lilliefors test was applied to ensure Gaussian distribution of all results. Two-way analysis of variance (ANOVA, time \times conditions) was used to analyse the influence of the exercise duration (time) under the different experimental conditions. When a significant effect was detected, a post-hoc comparison was made using the LSD Fisher test. The agreements between the incremental test and the TT4 tests were initially determined using linear regression, and Pearson's coefficient correlation (r) was expressed. Then, Bland and Altman's [7] method was used to compare the different methods of assessing PO and evaluate whether there was an agreement or bias among the methods. The limits of agreement were defined as means \pm 1.96SD. Additionally, we used effect size (ES, Cohen's d), which represents the ratio of the mean difference over the pooled variance, to estimate the magnitude of the difference. As Cohen proposed [9], the difference was considered trivial when $ES \leq 0.2$, small when $ES \leq 0.5$, moderate when $ES \leq 0.8$, and large when $ES > 0.8$. The coefficient of variation (CV) of PO was computed under the different conditions considered herein. Statistical significance was assumed for a p-value of less than 0.05.

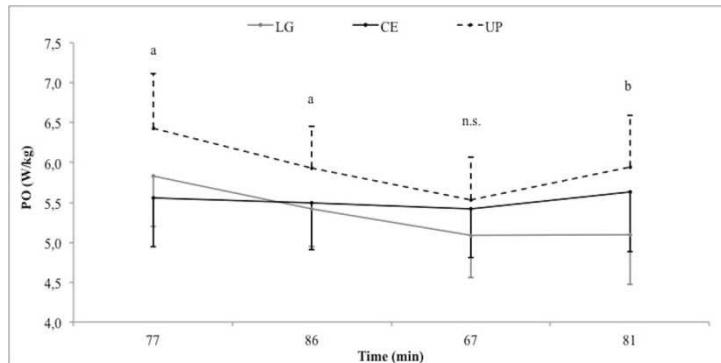
Results

Effect of cycling conditions on PO

The two-way analysis of variance indicates that there was no significant interaction between time and PO under all cycling conditions. However, time interacted with PO under the UP ($p < 0.05$) and LG ($p < 0.001$) conditions (fig. 1). The mean PO was significantly higher ($p < 0.001$) under UP ($6.0 \pm 0.5 \text{ W} \cdot \text{kg}^{-1}$) compared with that under CE (+8.0%) and LG (+11.0%).

Different pacing strategies were observed with a fast start under UP and LG and a final spurt under UP and CE (fig. 1). Indeed, during the first two-thirds of the effort, PO decreased gradually under UP compared with that under LG ($p < 0.05$) and CE ($p < 0.001$). This trend

was observed under LG, too. It appears that the pacing strategy under CE was the most consistent. The CV values of PO under UP (14.1%) and LG (14.5%) were higher than that under CE (6.8%).



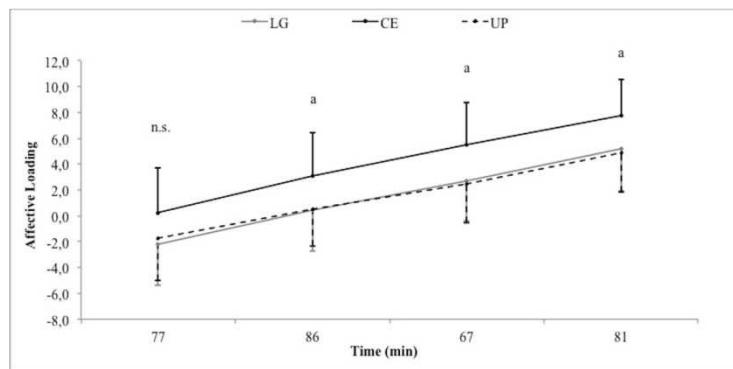
Effect of cycling conditions on heart rate and cadence

The results of two-way ANOVA indicate that there was no significant interaction of time with HR and cadence under all cycling conditions. However, there was an effect of time on HR ($p < 0.001$) under CE, LG and UP. The mean HR was not significantly different among the cycling conditions.

There was no effect of time on cadence. The mean cadence was significantly higher ($p < 0.001$) under CE (103.8 ± 6.8 rpm) compared with that under LG (+11.1%), and the latter was significantly higher ($p < 0.001$) than that under UP (+17.0%).

Effect of cycling conditions on affective load

The two-way ANOVA indicates that there was no significant interaction of time with PE, pleasure, and AL under all cycling conditions. However, there was an effect of time on AL ($p < 0.001$) (fig. 2) and PE ($p < 0.001$) under all conditions, but only on pleasure under CE ($p < 0.05$) and LG ($p < 0.05$). The mean PE was significantly higher under CE (7.1 ± 1.7) compared with that under LG (+18.3%) and UP (+16.4%), whereas the mean pleasure was significantly lower under CE (3.0 ± 2.0) compared with that under LG (-33.8%) and UP (-35.2%). In terms of the difference between PE and pleasure, the mean AL was significantly higher under CE (4.1 ± 3.2) compared with that under LG (+171.1%) and UP (+169.4%).



Comparison between MAP test and various TT4 tests

Table 1 lists the main results of the MAP test and the various TT4 tests for PO, HR_{max} , and cadence.

Table 1 Correlations, limits of agreement, and effect size for PO, HR_{max} , and cadence between the MAP test and the TT4 tests realised under the following experimental conditions: cycle ergometer (CE), level ground (LG), and uphill (UP).

Condition	PO (W)	PO ($\text{W} \cdot \text{kg}^{-1}$)	HR_{max} (bpm)	Cadence (rpm)
MAP Test	360.8 ± 42.4	5.3 ± 0.6	191.2 ± 8.1	
CE TT4	378.1 ± 50.9	5.5 ± 0.6	190.9 ± 5.9	103.8 ± 6.8
<i>Correlation</i>	0.96 **	0.94 **	0.75 *	
<i>Bias</i>	17.4	0.2	-0.3	
<i>LoA</i>	-12.1–46.8	-0.2–0.7	-10.9–10.2	
<i>Effect Size</i>	0.18	0.20	0.02	
<i>Interpretation</i>	Trivial	Trivial	Trivial	
LG TT4	367.3 ± 37.5	5.4 ± 0.5	183.2 ± 7.7	93.4 ± 6.4
<i>Correlation</i>	0.76 *	0.71 *	0.79 *	
<i>Bias</i>	6.5	0.1	-8.0	
<i>LoA</i>	-49.0–62.0	-0.7–0.9	-18.0–2.0	
<i>Effect Size</i>	0.08	0.09	0.45	
<i>Interpretation</i>	Trivial	Trivial	Small	
UP TT4	408.3 ± 45.2	6.0 ± 0.5	186.6 ± 6.1	79.9 ± 5.6
<i>Correlation</i>	0.89 **	0.87 **	0.75 *	
<i>Bias</i>	47.5	0.7	-4.6	
<i>LoA</i>	-7.3–87.7	-0.1–1.2	-15.1–5.9	
<i>Effect Size</i>	0.48	0.54	0.31	
<i>Interpretation</i>	Small	Moderate	Small	

* Significant at $p < 0.05$; ** Significant at $p < 0.001$; LoA = Limits of Agreement

Discussion

The main findings of this study show that during a TT4 test, the PO is dependent on the total resistance to the locomotion, which alters the pacing strategy used by cyclists according to

their AL. PO appears to be a relevant predictor of MAP when the measurement is performed as a TT4 test under CE and LG.

The results indicate that the validity of the MAP measured via incremental exercise in a laboratory depended on the nature of the TT4 tests. The significant correlations and the trivial ES observed between MAP and PO under LG suggest that these two conditions are relevant for determining MAP in the field. The correlation between MAP and PO in the LG TT4 test agrees with the results of a previous study by Nimmerichter *et al.* [25] on performance assessment by means of an incremental test and maximal 4-min flat tests. Another recent study [19] validated a field protocol in a velodrome for measuring MAP comparing both laboratory and field incremental tests. However, the field assessment was realised under velodrome conditions, which cannot be integrated easily into athletes' training routines.

The changes in PO among the three conditions could likely be ascribed to the different resistances opposing locomotion. Indeed, under LG, the most important resistance is aerodynamic drag [24]; under UP, it is gravity, and under CE, it is the break of the ergometer. All these conditions involve changes in crank inertial load, which can alter the biomechanical (crank torque profile, preferred pedalling cadence, gross efficiency) and physiological measurement outcomes [3, 4, 16, 20, 21]. It has been shown previously that the cycling ergometers used in the laboratory generate different ranges of crank inertial load owing to different gear ratios and flywheel inertia [17]. Several professional cycling coaches who use PO measurements to optimise training sessions reported differences in performance according to the nature of the terrain. They observed that the measured performance under laboratory conditions was generally lower by 30–50 W over a 20-min time trial compared with that in training tests under outdoor conditions (especially under UP) [5]. In this study, PO in the UP TT4 test was 41 W (11.2%) upper compared in LG. This result is higher than the result of Padilla *et al.* [26] and Vogt *et al.* [32] who noted smaller differences of 4.5% and 3.6% respectively. However, this difference was in accordance with the results of another study by Vogt *et al.* [33], which was conducted during the 2005 Giro d'Italia (13.4%).

Because pedalling cadence was free, the results indicate significant differences in cadence under all cycling conditions. Our findings agree with those of Emanuele & Denoth [13] who studied the influence of road incline and body position on the power–cadence relationship, as well as with those of Bertucci *et al.* [5] who showed that the preferred pedalling cadence was higher under CE compared with that under LG (+11.1%) and UP (+30%). Finally, the mean

HR response measured during all TT4 tests followed a cardiovascular drift, but there was no significant difference among the conditions.

Time had no effect on the pacing strategy in the CE TT4 test, but its effect was observed under road cycling conditions in the LG ($p < 0.001$) and UP ($p < 0.05$) tests. The CV was lower under CE (6.8%) compared with that under LG (14.5%) and UP (14.1%). This suggests that the PO fluctuations were more important under road cycling conditions. Indeed, during field locomotion, cyclists must account for several environmental and topographic parameters, which may bring about changes in the resistances opposing the motion. Moreover, to maximise their level of performance, cyclists must race at the optimal intensity determined, in part, by the nature of the task and their own physiological and psychological capabilities.

AL increased linearly with duration ($p < 0.001$) under all conditions. This result is in accordance with the literature. Indeed, when exercise is maintained until fatigue, the induced physiological responses increase AL, thereby reducing the conscious desire to maintain the exercise intensity [2]. The athlete must monitor not only the physiological reserves but also AL to ensure that catastrophic failure of any physiological or emotional system does not occur before the end of the effort. Alternatively, AL may represent a part of brain control that contributes to pacing strategy regulation.

Likewise, AL was significantly higher ($p < 0.001$) under the CE indoor condition compared with the field conditions in the LG (+171.1%) and UP (+169.4%) tests. This is explained by both the higher PE and the lower pleasure in this mode of locomotion. The higher AL under CE could be because of changes in mechanoreceptor stimulation in the lower limbs due to the specific pedalling biomechanics on the ergometer [4, 27]. Indeed, under CE, the cyclists did not exercise in their usual pedalling condition, and this could have affected their PE and pleasure. Another possible reason for the different PE and pleasure found under CE could be changes in the exercise environment. As Rejeski stated [30], the preference of an individual for a particular mode of exercise has a major influence on PE. Indeed, if an individual views a particular activity as distasteful, they might rate that activity as requiring greater effort than other activities of equal intensity.

In conclusion, this study showed that the PO in a TT4 test depends on both the pedalling condition and the associated pacing strategy established by the cyclist. It is a relevant predictor of MAP when measured under the CE and LG conditions. Accordingly, it seems to be important to measure MAP by accounting for the cycling conditions considering that this

parameter is used by coaches and scientists to assess the aerobic potential of athletes and to determine exercise intensities useful for monitoring adaptation to training.

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CHAPITRE 6 : Etude de la technique en danseuse en rapport à la $P_{méca}$ développée au niveau du centre de masse et celle utile à l'avancement

Les résultats de ce travail ont fait l'objet d'un article soumis dans la revue *Medicine and Science in Sports and Exercise* : « World-class climber has a more efficient standing technique in uphill cycling ».

Résumé détaillé

World-class climber cyclist has a more efficient standing technique in uphill cycling

Pinot J, Candau R, Rinaldi K et Grappe F

Etat de l'art : En montée, l'étude de la position du cycliste est un paramètre important sur lequel la littérature scientifique reste pauvre. Bien que plusieurs études se soient intéressées à analyser les différences physiologiques entre les positions assis et danseuse (Swain et Wilcox, 1992 ; Tanaka *et al.*, 1996 ; Millet *et al.*, 2002 ; Fonda et Šarabon, 2012) , leurs résultats divergent sans prendre en considération les différences interindividuelles comme le niveau de pratique, les qualités du cycliste ou son profil performance en compétition. Il est clairement établi que la position en danseuse favorise les performances sur des efforts courts et intensifs (Millet *et al.*, 2002 ; Hansen et Waldegaard, 2008) alors que les résultats sont contradictoires quand à la stratégie la plus efficiente dans le choix entre les deux postures sur les efforts plus longs à intensité constante. Dans ce sens, notre précédente étude a montré que la $P_{méca}$ mesurée lors d'un test maximal 4 min en montée était supérieure à celle mesurée sur le plat alors que les cyclistes avaient la possibilité d'alterner les positions assis et danseuse. A haut niveau, il n'y a pas de règle commune entre les grimpeurs de classe mondiale, certains étant souvent en danseuse alors que d'autres très rarement. A notre connaissance, aucune étude n'a rapporté une technique en danseuse plus efficiente chez des cyclistes de haut niveau. L'analyse du mouvement du centre de masse (CM) pour évaluer le travail potentiel (W_{pot}) et cinétique (W_{cin}) chez des cyclistes devrait permettre d'apporter une meilleure compréhension de la technique utilisée en danseuse. En effet, l'évolution des niveaux d'énergie cinétique et potentielle du CM permet de déterminer le travail mécanique externe (W_{ext}) produit par le

cycliste qui représente un paramètre majeur du travail mécanique de la locomotion (Cavagna, 1975 ; Pfau *et al.*, 2005).

Objectif : L'objectif de cette étude était de comparer la $P_{\text{méca}}$ externe du centre de masse ($P_{\text{méca-CM}}$), l'efficacité mécanique (EM) et le transfert entre les énergies potentielle et cinétique (TE) en position de danseuse lors d'un effort en montée à intensité soutenue sur différentes pentes entre un cycliste de classe mondiale et un groupe de cyclistes élites non grimpeurs. L'hypothèse de départ était que la technique en danseuse utilisée par le cycliste de classe mondiale pouvait être particulière en optimisant l'EM et les mécanismes de conservation de l'énergie en transformant l'énergie potentielle en cinétique.

Méthodes : Un grimpeur de classe mondiale et 12 cyclistes de haut niveau ont participé à cette étude. La mesure de $P_{\text{méca-CM}}$ a été réalisée à l'aide d'un bras cinématique (Belli *et al.*, 1992). L'exercice se déroulait avec le vélo personnel de chaque cycliste équipé d'une roue arrière possédant un capteur de puissance Powertap sur un tapis roulant motorisé. Après une séance d'habituation sur le tapis, chaque cycliste effectuait 4 paliers de 2 min sur 4 pentes différentes (5, 7, 9 et 11%) à des vitesses normalisées en fonction d'une $P_{\text{méca}}$ constante équivalente à 4,6 W/kg. Trois enregistrements de 8 sec en position de danseuse étaient effectués lors de chaque palier. $P_{\text{méca-CM}}$ était obtenue à partir de la mesure du bras cinématique qui permettait de calculer les niveaux d'énergie potentielle et cinétique en danseuse. L'indice d'EM était calculé à partir du ratio entre la $P_{\text{méca}}$ effective mesurée par le capteur de puissance et $P_{\text{méca-CM}}$ alors que l'indice de TE était obtenu à partir des calculs des $P_{\text{méca-pot}}$ et $P_{\text{méca-cin}}$.

Résultats : Les paramètres biomécaniques différaient entre le grimpeur de classe mondiale et les cyclistes élites non grimpeurs en position de danseuse. La $P_{\text{méca-CM}}$ diminuait significativement en fonction de la pente pour les non-grimpeurs alors qu'elle avait tendance à augmenter pour le grimpeur de classe mondiale. Sur les pentes de 5 - 7%, la $P_{\text{méca-cin}}$ était deux à quatre fois supérieure à $P_{\text{méca-pot}}$ chez les non-grimpeurs alors qu'elle était similaire chez le grimpeur de haut niveau. Sur les pentes de 5 - 7%, l'EM du grimpeur était significativement supérieure à celle des non grimpeurs (+115% sur les pentes de 5% et +88% sur les pentes de 7%) alors que sur les pentes de 9 - 11%, l'EM du grimpeur était légèrement inférieure respectivement de 22 et 24%. En ce qui concerne l'indice de TE, il était beaucoup plus élevé chez le grimpeur de classe mondiale sur les pentes de 5 – 7% (+299% et +514%). Il semble que EM soit positivement corrélé aux TE, mais les corrélations obtenues n'étaient pas significatives ($p = 0,15$) à la fois pour le grimpeur et les non-grimpeurs.

Discussion : Cette étude originale est la première à mesurer $P_{méca-CM}$ en cyclisme en conditions réelles de pratique sur un tapis roulant. Les importantes différences interindividuelles dans les variables biomécaniques en danseuse ont montré qu'il existe un grand nombre de techniques utilisées par les cyclistes en montée lors d'efforts soutenus. Ces observations vont dans le sens de l'étude de Millet *et al.* (2002) qui suggérait que les caractéristiques techniques et le niveau d'expertise avaient une influence sur la dépense énergétique en position de danseuse.

Les adaptations biomécaniques étaient différentes entre le grimpeur de classe mondiale et les cyclistes non-grimpeurs en fonction de la pente pour une même intensité d'effort. L'EM de l'ensemble des cyclistes se situait entre 23% et 52%. Ce résultat montre qu'en danseuse, les mouvements du CM produisent une importante quantité de travail externe, largement supérieur au travail effectif mesuré au niveau du vélo.

De manière surprenante, en montée, le W_{cin} des non-grimpeurs était toujours supérieur au W_{pot} , alors que ce fut uniquement le cas dans les pentes les plus raides (9 - 11%) pour le grimpeur de haut niveau. Cette variation plus élevée de l'énergie cinétique par rapport à l'énergie potentielle est une caractéristique importante du cyclisme en montée, directement relié à l'efficacité du cycle de pédalage et à la transmission des forces au niveau de la pédale.

Sur les pentes les plus couramment rencontrées en compétition (5 - 7%), le grimpeur de classe mondiale avait une EM et un TE significativement plus élevé. Il semble qu'il existe une tendance montrant une relation pertinente entre l'EM et le TE pour tous les cyclistes, suggérant que plus le TE est élevé, plus l'EM augmente. Ainsi, il apparaît que la principale différence résiderait dans une plus grande capacité à transférer l'énergie potentielle en cinétique avec une cadence optimale, ce qui était le cas du grimpeur de classe mondiale sur les pentes de 5 – 7%. Sur les pentes les plus raides (9 – 11%), l'EM et les TE du grimpeur de classe mondiale étaient altérés. Il semble que cela soit dû à la diminution de la cadence.

Ainsi, une technique en danseuse efficace semble être reliée avec une EM et un TE élevés associés à une cadence optimale en fonction de la pente. Sur les pentes les plus élevées, la technique en danseuse du grimpeur est apparue moins efficiente alors que le RPE était constant. Ce constat suggère que sur les pentes raides avec des cadences plus faibles, le grimpeur de classe mondiale utilise une technique en danseuse qui pourrait favoriser le phénomène d'un cycle étirement-détente au niveau des membres inférieurs, comme cela l'a déjà été observé en cyclisme précédemment (Hull et Hawkins, 1990 ; Bini et Diefenthäler,

2009). Cette supposition demande évidemment à être scientifiquement confirmée dans d'autres études.

Conclusion : Le résultat principal de cette étude montre que lors d'un effort soutenu en montée, une technique en danseuse efficiente, comme celle du grimpeur de classe mondiale, semble être associée à une EM et un TE élevés. Comparé aux cyclistes élites non grimpeurs, le grimpeur de classe mondiale possède une technique en danseuse plus efficiente sur les pentes les plus couramment rencontrées de 5 et 7% avec des cadences élevées. De futures études sont nécessaires pour relier EM et TE avec le coût énergétique du déplacement en danseuse.

Medicine & Science in Sports & Exercise

World-class climber cyclist has a more efficient standing technique in uphill cycling

--Manuscript Draft--

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Abstract:	Purpose: The purpose of this study was to compare the external mechanical power of the center of mass (PCM-ext), the mechanical efficiency (ME), and transfers between potential and kinetic energy (ET) in the standing position between a world-class (WC) climber and a group of non-climber elite cyclists. Methods: A WC climber, top-ten finisher of Grand Tours, and 12 high-level cyclists performed three bouts of 30 seconds in the standing position on a motorized treadmill at four slopes (5, 7, 9, and 11%) and at a moderate intensity (4.6 W/kg). The ME and ET in the standing position were calculated by using the effective power output (Pbike), measured by a PowerTap hub, and the PCM-ext, measured from a kinematic arm (KA) that measured the displacement of the cyclist's CM. Results: The biomechanical variables differ between the WC climber and the non-climber cyclists in the standing position. The PCM-ext decreased significantly according to the slope ($r=-0.98$, $p<0.05$) for the non-climber cyclists whereas it tended to increase for the WC climber. The results highlight that on the slopes of 5-7%, the PCM-kin for the no-climber cyclists was twice to four times higher than the PCM-pot, while for the WC climber, the PCM-kin and PCM-pot were similar. Furthermore on these slopes, the ME and ET of the WC climber were two and five times higher, respectively than those of the non-climber cyclists. Conclusion: This study demonstrated that during uphill cycling an efficient standing technique seems to be associated with high ME and ET. The results show that compared to the non-climber cyclists, the WC climber has a more efficient standing technique on the most frequently encountered slopes (5-7%).

Title: World-class climber cyclist has a more efficient standing technique in uphill cycling

ABSTRACT

Purpose: The purpose of this study was to compare the external mechanical power of the center of mass (P_{CM-ext}), the mechanical efficiency (ME), and transfers between potential and kinetic energy (ET) in the standing position between a world-class (WC) climber and a group of non-climber elite cyclists. **Methods:** A WC climber, top-ten finisher of Grand Tours, and 12 high-level cyclists performed three bouts of 30 seconds in the standing position on a motorized treadmill at four slopes (5, 7, 9, and 11%) and at a moderate intensity (4.6 W/kg). The ME and ET in the standing position were calculated by using the effective power output (P_{bike}), measured by a PowerTap hub, and the P_{CM-ext} , measured from a kinematic arm (KA) that measured the displacement of the cyclist's CM. **Results:** The biomechanical variables differ between the WC climber and the non-climber cyclists in the standing position. The P_{CM-ext} decreased significantly according to the slope ($r=-0.98$, $p<0.05$) for the non-climber cyclists whereas it tended to increase for the WC climber. The results highlight that on the slopes of 5-7%, the P_{CM-kin} for the no-climber cyclists was twice to four times higher than the P_{CM-pot} , while for the WC climber, the P_{CM-kin} and P_{CM-pot} were similar. Furthermore on these slopes, the ME and ET of the WC climber were two and five times higher, respectively than those of the non-climber cyclists. **Conclusion:** This study demonstrated that during uphill cycling an efficient standing technique seems to be associated with high ME and ET. The results show that compared to the non-climber cyclists, the WC climber has a more efficient standing technique on the most frequently encountered slopes (5-7%).

Keywords: ELITE CYCLISTS; BIOMECHANICS; PEDALLING TECHNIQUE; UPHILL TERRAIN PERFORMANCE.

INTRODUCTION

In the optimization approach of cycling performance, the cyclist's position on the bicycle is an important parameter in which the sport sciences literature remains poor, especially for uphill terrains. Although numerous studies have attempted to analyze the physiological differences between seated and standing cycling (Swain et Wilcox, 1992 ; Tanaka *et al.*, 1996 ; Millet, Tronche, *et al.*, 2002 ; Fonda et Šarabon, 2012), their conflicting results did not take

into account the inter-individual differences due to the level of practice, the skills of the cyclists, and their profile. It is well-established that the standing position favors performance during intensive bouts of uphill cycling (Millet, Tronche, *et al.*, 2002 ; Hansen et Waldeland, 2008). However, during uphill steady-state cycling, the results are contradictory on the most efficient strategy in the choice between the two postures. When a cyclist climbs a hill, he may stand or remain seated according to many factors, such as the gradient and the length of the hill, available gearing, pacing strategy, individual experience, body morphology and preference (Harnish *et al.*, 2007). Physiological factors such as energy cost, local muscle fatigue, and muscle perfusion could also determine the choice between seated and standing cycling performance (Millet, Tronche, *et al.*, 2002).

In high-level cycling, there is no common rule among the best world-class (WC) cycling climbers. Some remain seated and stand up when they attack, whereas others prefer switching between standing or seated positions in various proportions. Likewise, to the best of our knowledge, no systematic studies have reported any characterization of an efficient standing technique or a technique used by WC climbers. Several studies described generalities of the standing position in comparison with the seated posture. Simple visual observations reveal that cyclists use different techniques in the standing position, and during the uphill steady-state, the time spent in the seated or standing positions varies. Some WC climbers are able to stay in the standing position a relatively long time, indicating that their technique is certainly optimized for efficiency. An efficient technique could correspond to the implementation of coordination patterns in order to optimize both the ratio between the effective work and the total work, that is, the mechanical efficiency (ME), and the exchanges between potential and kinetic energy (ET). To the best of our knowledge, no study has investigated the biomechanical analysis of body movements between a WC climber and non-climber elite cyclists at a moderate intensity commonly used in mountain ascents. Analyzing the motion of the center of mass (CM) to assess the potential (W_{pot}) and kinetic works (W_{kin}) in a WC climber and comparing this to non-climber elite cyclists would allow for a better understanding of the technique used in the standing position. Indeed, the changes in the potential and kinetic energy levels of the CM allow for determining the external mechanical work (W_{ext}) performed by the cyclist during the cyclic movement, with W_{ext} representing a major component of the mechanical work of locomotion (Cavagna, 1975 ; Pfau *et al.*, 2005).

The purpose of this study was to compare the external mechanical power of the CM (P_{CM-ext}), ME, and ET in the standing position according to different slopes (5, 7, 9, and 11%) between a WC climber and a group of non-climber elite cyclists at a moderate intensity commonly

used in mountain ascents. The P_{CM-ext} was computed using a kinematic arm (KA) that measured the displacement of the cyclist's CM in the standing position on a treadmill. We hypothesized that the mechanical energy associated with the oscillatory movements of the WC climber's body is singular and optimizes the ME and the mechanisms of energy conservation by transforming the potential energy into kinetic energy. Thus, WC climber would have his own technique compared to the other cyclists.

METHODS

Subjects

A WC climber cyclist, top-ten finisher of Grand Tours (Tour de France and Vuelta a España) and World Tour stage races, volunteered to participate in this study. His age, height, body mass and maximal oxygen consumption were 23 yrs, 1.80 m, 65 kg, and 85 mL/min/kg, respectively. The population of non-climber cyclists was composed of 12 trained, healthy, male, high-level cyclists belonging to professional teams or ranked among the highest amateur level of the country. The age, height, and body mass of the tested subjects were 23 ± 4 (mean \pm SD) yrs, 1.77 ± 0.06 m, and 66 ± 8 kg, respectively. Before the experiment, each subject received full explanations concerning the nature and the purpose of the study. The participants provided written informed consent to participate in this study, which was approved by a University Human Research Ethics Committee. The study meets the international ethical standards described by the Declaration of Helsinki of the World Medical Association.

Experimental design

The study comprised one testing session in which each subject cycled with his own racing bicycle on a large motorized treadmill (S 1930, HEF Techmachine, Andrezieux-Boutheon, France) of 3.8 m length and 1.8 m width at different slopes (5, 7, 9, and 11%). Slopes of 5-7% are mainly observed in mountain ascents in competitions such as the Tour de France. Slopes of 9-11% are more commonly observed in several mountain ascents in Spain and Italy. The bicycle tire pressure was inflated to 700 kPa.

Before testing, all the subjects performed several trials on the motorized treadmill to get used to the equipment. The protocol started when the subjects felt comfortable in the standing position as in real locomotion. We verified this by the mean of a standard comfort scale,

graduated from 0, "I feel uncomfortable", to 10, "I feel perfectly comfortable", and started when they gave a rating of at least 8.

Power output measurements

Each bike was fitted with the same rear wheel composed of a PowerTap hub (CycleOps, Madison, USA). The PowerTap device is a valid and reliable mobile power meter that measures the power output (P_{bike}) inside the hub, the velocity, and the pedaling cadence. (Gardner *et al.*, 2004 ; Bertucci *et al.*, 2005).

Kinematic arm measurements

The KA method measures the body displacements in the three spatial dimensions at the pelvis level (Belli *et al.*, 1992 ; Belli *et al.*, 1993 ; Belli *et al.*, 1995 ; Bourdin *et al.*, 1995 ; Candau *et al.*, 1998). The KA allows for performing computations of velocities, accelerations, forces, and one other important application of this approach, which is the quantification of W_{ext} and $P_{\text{CM-ext}}$. The KA consists of four rigid bars linked together by three mono-axial joints. One end of the KA was connected to a reference point (reference end) and the other end moved freely in the three spatial directions (moving end). At each joint, an optical transducer interfaced to a personal computer measured the joint angles. Knowing the bar lengths and the joint angles, an appropriate trigonometric equation could be applied to compute the instantaneous position of the moving end relative to the reference end. The KA principle and its validation have been described in detail in previous studies (Belli *et al.*, 1992 ; Belli *et al.*, 1993 ; Belli *et al.*, 1995 ; Bourdin *et al.*, 1995 ; Candau *et al.*, 1998). In order to apply the KA method to cycling, the measuring end of the KA was linked to the subject by means of a belt fastened around his waist, while the reference end was fixed to the ceiling (Figure 1). The displacement of the treadmill belt was measured using an extra optical encoder fixed to a wheel mounted on the treadmill belt with an accuracy of 0.1 mm. The velocity of the treadmill was obtained by a first-order digital derivation of the displacement signal. The signals were recorded on a personal computer (Victor 486 SX33) through a 12-bit data-conversion system especially designed for this purpose.

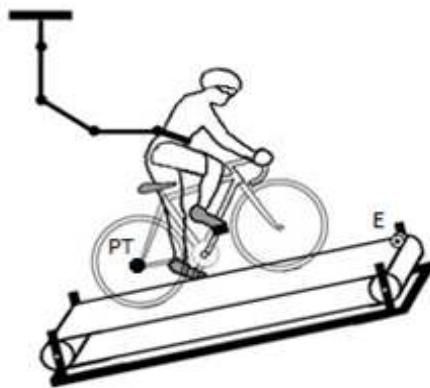


Figure 1: Illustration of the cyclist fitted with the kinematic arm around his waist on the treadmill; the caster E represents the extra optical encoder fixed to the wheel mounted on the treadmill belt and the PowerTap hub is schematized by the circle PT at the rear wheel.

Standing cycling trials

The testing protocol consisted of four consecutive trials of five minutes' uphill cycling at the four slopes. The order of trials at each gradient were randomized in order to avoid any tiredness effect the more the slope increased. The speed of the treadmill was individualized during each trial such that each subject performed at the target power output of 4.6 W/kg. This intensity corresponded to a moderate intensity for everyone, that is, an intensity that can be sustained for at least one hour and commonly used in mountain ascents. At the end of each trial, the subjects indicated their rating of perceived exertion (RPE) using the Borg CR10 scale (Borg, 1990). All subjects were equipped with the same gear cluster, which included a 27 cog that produced a minimum gear size of 3.03 m per pedal revolution. This cluster is the one usually used by cyclists in training and competition. The subjects could choose their preferred cadence but they had to keep the same gear ratio on each slope.

In each trial, the subjects realized three bouts of 30 seconds in the standing position, alternating with the seated position in order to mimic real locomotion. The KA measurements were performed only during each standing bout. The sampling duration and frequency were 8 s and 100 Hz, respectively. The PowerTap data were collected during the same time. At the end of the session, 12 files of the KA and 12 bouts in the PowerTap file were collected and analyzed.

Quantification of the mechanical external power of CM

The anatomical localization of the CM is complex because of the possible tilting movements of the trunk. We observed that they were limited; thus, we assumed that the waist movements were a reasonable approximation of the CM displacements as proposed by Fenn (Fenn, 1930),

and based on trigonometric equations that have been described in detail by Belli *et al.* (1992), the position of the CM was computed.

During human locomotion, potential (W_{pot}) and kinetic works (W_{kin}) correspond to positive potential and kinetic energy changes (Cavagna, 1975). W_{pot} and W_{kin} of the CM are obtained from the vertical position (h), and the horizontal velocity of the CM (v), respectively:

$$W_{pot} = m_b g (h_{max} - h_{min})$$

$$W_{kin} = 0.5 m_b (v_{max}^2 - v_{min}^2)$$

where m_b is the body mass (kg), g is the acceleration due to gravity (9.81 m.s⁻²), h_{max} and h_{min} are the maximal and minimal heights of the CM (m) according to the vertical displacements relative to the ground and the elevation with the slope of the climb, respectively, and v_{max} and v_{min} are the maximal and the minimal horizontal velocities of the CM (m/s).

The instantaneous external mechanical energy was calculated by the addition of the potential and kinetic energy levels. Then, W_{ext} was calculated from the positive external mechanical energy changes. The mechanical external power of the CM (P_{CM-ext}), potential power (P_{CM-pot}), and kinetic power (P_{CM-kin}) were calculated (in W/kg) as follows:

$$P_{CM-ext} = W_{ext} / t$$

$$P_{CM-pot} = W_{pot} / t$$

$$P_{CM-kin} = W_{kin} / t$$

where t represents the time for one-half revolution of pedal.

The index of ME was calculated as the ratio between the effective power (i.e., P_{bike} , and P_{CM-ext}). The index of ET was obtained as follow:

$$ET = 1 - [P_{CM-ext} / (P_{CM-pot} + P_{CM-kin})]$$

Statistics

Statistical analysis was performed using SigmaPlot 12.0 software (Systat Inc., San Jose, USA). Descriptive statistics were used and all data were expressed as mean \pm standard deviation, [min - max], (coefficient of variation). Pearson zero-order correlation coefficients were computed by the least-squares method to describe the relationship between selected variables. The normality of values distributions were assessed with the Kolmogorov-Smirnov test. One-way analysis of variance (ANOVA) was used to analyze the differences of P_{CM-ext} according to the slope in the group of non-climber cyclists. When a significant effect was

detected, a post-hoc comparison was made using Fisher's least significant difference test. The statistical significance was set at $p < 0.05$.

RESULTS

An example of variations in the potential, kinetic, and external energy levels of the CM, during one revolution of pedal, is given for a representative subject in Figure 2. There were marked differences between the kinetic and potential energy levels. This is emphasized by the scales shown in Figure 2. The kinetic energy was maximal when the crank was horizontal, whereas it was minimal during the phases of low and high transitions (Hull *et al.*, 1990). Potential and kinetic energies were partly out of phase indicating the occurrence of an energy transfer mechanism during cycling.

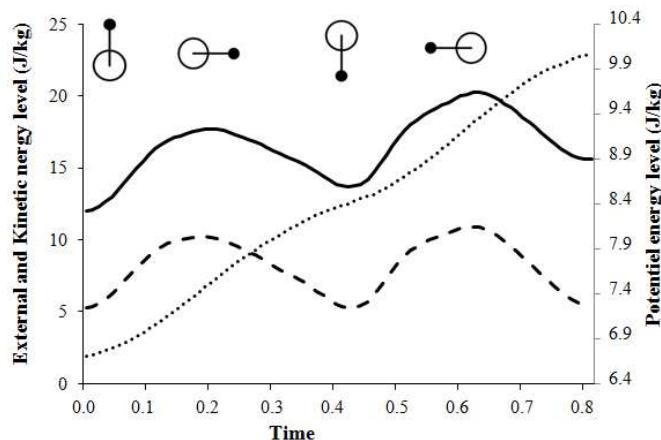


Figure 2: Example of the potential (dotted line), kinetic (dashed line), and external (solid line) energy levels during a pedal revolution at a slope of 9%.

A detailed analysis of biomechanical parameters for the group of non-climber cyclists and for the WC cycling climber is presented in Table 1. In the group of non-climber cyclists, the P_{CM-ext} was five to two times higher than the P_{bike} , respectively at 5% and 11%. The P_{CM-ext} decreased significantly according to the slope ($r = -0.98$, $p < 0.05$), whereas the P_{bike} remained unchanged. For the WC climber, the P_{CM-ext} was not significantly altered by the slope. There were important inter-individual differences in the P_{CM-ext} values for the non-climber cyclists since the coefficients of variation ranged from 35% to 52%. For the non-climber cyclists, the P_{CM-kin} were two to four times higher than the P_{CM-pot} , while for the WC climber, the P_{CM-kin} and P_{CM-pot} were similar on slopes of 5-7%. The preferred cadence decreased significantly

according to the slope for the non-climber cyclists ($r = -0.97, p = 0.01$) and the WC climber ($r = -0.98, p = 0.01$).

Table 1: Mean power values of the non-climber cyclists and the WC climber according to the slopes (* significantly different). Values of the group are expressed as mean \pm SD, [min - max], (CV).

(W/kg)	5%		7%		9%		11%	
	No-climbers	WC climber	No-climbers	WC climber	No-climbers	WC climber	No-climbers	WC climber
P_{bike}	4.6 \pm 0.3 [4.3 - 5.0] (5%)	4.6	4.6 \pm 0.2 [4.3 - 4.8] (7%)	4.5	4.6 \pm 0.2 [4.5 - 4.9] (6%)	4.6	4.7 \pm 0.2 [4.5 - 4.9] (6%)	4.7
$P_{\text{CM-ext}}$	19.9* \pm 10.4 [7.1 - 33.2] (52%)	9.2	16.6 \pm 7.6 [6.6 - 28.8] (46%)	8.65	14.3 \pm 5.7 [6.1 - 23.1] (40%)	18.3	12.6 \pm 4.4 [6.2 - 20.2] (35%)	16.5
$P_{\text{CM-pot}}$	4.3 \pm 0.6 [3.7 - 5.2] (13%)	5.2	4.6 \pm 0.9 [3.7 - 6.9] (19%)	5.7	4.8 \pm 0.7 [4.1 - 6.0] (14%)	4.7	5.0 \pm 0.7 [4.5 - 6.6] (14%)	5.1
$P_{\text{CM-kin}}$	16.2* \pm 10.4 [2.9 - 29.4] (64%)	5.3	12.4 \pm 7.7 [2.1 - 24.3] (62%)	4.4	10.1 \pm 5.7 [1.6 - 18.7] (56%)	14.2	8.2 \pm 4.5 [1.1 - 15.5] (56%)	13.3

Figure 3 shows that the ME of the non-climber cyclists increased significantly according to the slope ($r = 0.99, p < 0.05$), from 23.1% (slope of 5%) to 37.3% (slope of 11%), while for the WC climber, the ME was not significantly altered by the slope. On the most frequently encountered slopes (5-7%), the ME of the WC climber were significantly higher (115% and 88%) than the ME of the non-climber cyclists. Conversely, on the slopes of 9-11%, the ME of the WC climber cyclists were lower (-22% and -24%) than those of the non-climber cyclists.

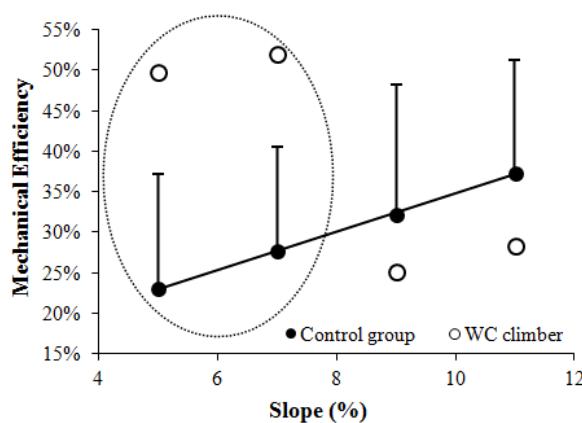


Figure 3: Relationships between the slope and the mechanical efficiency of the non-climber cyclists ($r = 0.99, p < 0.05$) and the WC climber ($r = -0.83, p = 0.16$). The dotted circle shows the ME in the slopes mainly observed in mountain ascents (5-7%).

Figure 4 shows that there was no significant change of ET according to the slope for all the cyclists. However, the ET of the WC climber was clearly higher on the slopes of 5-7% (+299% and +514%) than the non-climber cyclists'.

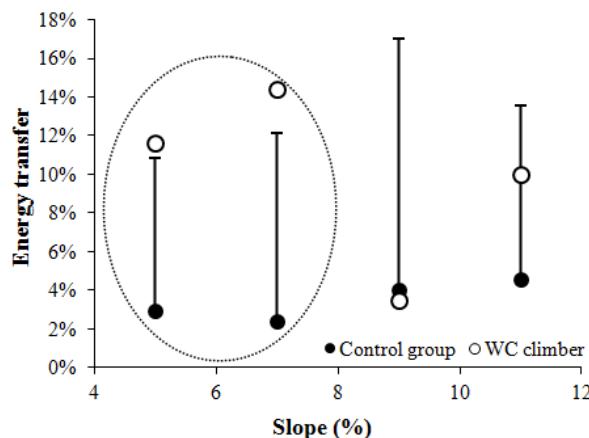


Figure 4: Relationships between the energy transfer index and the slope of the non-climber cyclists ($r = 0.84, p = 0.15$) and the WC climber ($r = -0.44, p = 0.55$). The dotted circle shows the ET in the slopes mainly observed in mountain ascents (5-7%)

Figure 5 shows that the ME seems to be linked with the ET, with a large difference on the most frequently encountered slopes (5-7%), but the correlations are not significant ($p = 0.15$) for both the WE climber and the non-climber cyclists.

In the group of non-climber cyclists, the RPE significantly increased ($p < 0.01$) according to the slope from 2.8 ± 0.5 to 4.4 ± 1.5 , whereas the P_{CM-ext} decreased. However, for the WC climber, the perceived exertion remained constant (2.5 to 3.0) with an increase of the P_{CM-ext} .

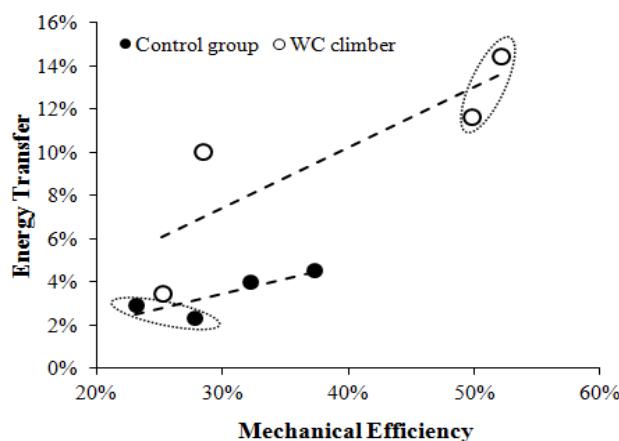


Figure 5: Relationships between the energy transfer index and the mechanical efficiency ($r = 0.84, p = 0.15$) for the non-climber cyclists and the WC climber. The dotted circle shows the ET and ME in the slopes mainly observed in mountain ascents (5-7%)

DISCUSSION

This is the first study that measures the P_{CM-ext} in real cycling conditions on a treadmill. The main result of this study clearly shows a higher ME (+100%) and ET (+394%) in the standing position for the WC climber compared to the non-climber cyclists on slopes of mountain ascents encountered most frequently (5-7%).

In a previous study, Millet *et al.* suggested that one cannot rule out that the technical characteristics and the high expertise level of the subjects had an influence on minimizing the energy expenditure when climbing in the standing position (Millet *et al.*, 2002). The large inter-individual differences in biomechanical variables in the standing position for the group of non-climber cyclists show that there were several standing posture techniques used by the cyclists to climb. These differences were observed both in terms of the changes in the potential and kinetic energy levels, and therefore, in the P_{CM-ext} values. These differences could explain the conflicting results reported in the previous studies about the physiological responses between the seated and standing positions (Swain et Wilcox, 1992 ; Tanaka *et al.*, 1996 ; Millet, Tronche, *et al.*, 2002 ; Harnish *et al.*, 2007 ; Fonda et Šarabon, 2012).

The biomechanical adaptations differ between the WC climber and the non-climber cyclists according to the slope of the ascent for the same intensity in the standing position. The ME of all of the cyclists ranged between 23% and 52% (i.e., the effective power output [P_{bike}] represented only 23% to 52% of the P_{CM-ext}). This result shows that in the standing position, the CM movements of the cyclists produce an important amount of external work, which was considerably higher than the effective work measured at the rear wheel hub on the bike.

It is interesting to observe that on the slopes of the most frequently encountered mountain ascents (5-7%), the P_{CM-kin} of the non-climber cyclists essentially represents the major part of the energy provided at the CM compared to the P_{CM-pot} . Surprisingly, in ascents, the kinetic work of the non-climber cyclists was two to four times higher than the potential work, although simple visual observations did not provide any substantial evidence of changes in the cyclist's speed during a pedal revolution. Precise measurements of the instantaneous speed of the rider are required in order to identify changes in speed within the pedaling cycle. This greater change in kinetic energy than in potential energy is an important feature of cycling locomotion on uphill terrain which is directly related to the fact that only the tangential force with respect to crank axis is useful for locomotion when the crank axis is near horizontal. The other positions of the crank are associated with a weak mechanical efficiency (i.e., weak effective propulsive force); the cyclist's velocity changes to a large extent on uphill terrain.

Leirdal and Ettema have shown that the evenness of power generation measured from the dead center (DC) size, defined as the minimal pedal work rate compared with the average work rate through the pedal cycle, is an important trait of energy-saving pedaling (Leirdal et Ettema, 2011). These authors reported that an uneven work rate generation will enhance acceleration and deceleration periods through the crank cycle. Thus, to help the cyclists maintain blood flow to the exercising muscles and decrease local fatigue, the fluctuations in work rate and force during the downstroke may be reduced while maintaining work rate. Therefore, the lower P_{CM-kin} of the WC climber observed in this study on the lowest slopes (5-7%) may improve the DC from a better efficiency in the pedaling cycle.

On the frequently encountered mountain ascents (5-7%), the WC climber had a significantly higher ME (+100%) and ET (+394%) than the non-climber cyclists. However, on the steeper slopes (9-11%), which are less frequent, he had a lower ME (-23%) despite a higher ET (+57%). It seems that there may be a relevant relationship between the ME and ET for all of the cyclists (Figure 5) with a higher slope for the WC climber, suggesting that compared to the non-climber cyclists, the more the ME of the WC climber increases, the higher his ET is. However, this trend requires further investigation to be confirmed. The results show that the WC climber is the most efficient on mountain ascents most commonly encountered (5-7%) with high and optimal cadences.

It appears that the difference between the WC climber and the non-climber cyclists resides in a greater ability to transfer the potential energy into kinetic energy. Moreover, it appears that the ME and ET of the WC climber could be altered on severe slopes which involve a decrease in the cadence. One can conjecture that both the ME and ET would be optimized with optimal cadences (> 80 rpm) on the steeper slopes. To achieve this, a specific gear is required which is not always available.

The present findings suggest that an efficient standing technique would be associated with high ME and ET on slopes of mountain ascents most frequently encountered (5-7%). On higher slopes (9-11%) with low cadences (60-70 rpm), the standing technique of the WC climber appears less efficient due to a decrease in both the ME and ET. In this condition, the increase of the P_{CM-ext} associated with a constant RPE could be due to the phenomenon observed by Hawkins and Hull and by Bini and Diefenthäler who demonstrated the presence of the stretch-shortening cycle in leg extensor muscles during cycling in the seated position (Hull et Hawkins, 1990 ; Bini et Diefenthäler, 2009). This suggests that the WC climber would use a standing technique on steeper ascents which allows for a slight elastic energy

storage-reuse in the muscular chains of the lower limbs. The anthropometrical characteristics of the WC climber, with a short trunk, long arms, slender pelvis and lower limbs, allow him to press down on the pedal by using his total body mass with a righted position and both oscillations of the pelvis and the trunk. Further studies are therefore necessary to test this hypothesis.

CONCLUSION

This study demonstrated that during uphill cycling at a moderate intensity, an efficient standing technique used by the WC climber seems to be associated with a high ME and transfers between potential and kinetic energy levels compared to the group of no-climbers. The results show that compared to the non-climber cyclists, the WC climber has a more efficient standing technique on the slopes of mountain ascents most frequently encountered (5-7%), with high cadences which involve a high ME and ET. Further studies are necessary to link the ME and ET with energy cost and performance in cycling locomotion.

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The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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DISCUSSION

Les études qui ont été conduites dans ce travail de thèse apportent une nouvelle approche méthodologique dans le suivi de l'entraînement en cyclisme à partir de la mesure de la $P_{méca}$. En effet, à partir d'une part, des connaissances acquises avec les travaux menés depuis le début du XX^{ème} siècle sur la relation entre l'intensité maximale d'un exercice et le temps et d'autre part, des résultats obtenus au cours de nos études, nous sommes en mesure de proposer un certain nombre d'applications pratiques permettant d'optimiser le suivi du cycliste à partir de l'analyse de la relation $P_{méca}$ – temps. Il convient de rappeler ici que dans le contexte de ce doctorant (CIFRE), une des missions qui m'a été confiée était de mettre en pratique les savoirs théoriques au service de l'amélioration du processus d'entraînement des cyclistes dans un but d'optimisation de la performance globale de l'équipe FDJ.

Le cyclisme est le seul sport où il est possible de mesurer en conditions réelles la $P_{méca}$. Le fait de pouvoir la mesurer précisément en dehors du laboratoire apporte aux études de terrain une réelle pertinence et crédibilité. En effet, la prise en considération des données obtenues en compétition permet d'apporter de nouvelles connaissances et de mieux appréhender les demandes spécifiques des compétitions de niveau mondial. Chez les athlètes de haut niveau, les facteurs motivationnels sont supérieurs sur le terrain, notamment en compétition, ce qui leur permet de réaliser des efforts d'une intensité maximale nettement supérieure à ce qu'ils seraient capable de produire dans des conditions de laboratoire. De plus, comme expliqué par Sassi *et al.* (2006) et Lamberts *et al.* (2010), les tests maximaux sont généralement perturbateurs et mal acceptés par les athlètes au cours de leur période de préparation, particulièrement lorsqu'ils sont proches des compétitions importantes. Par conséquent, l'analyse de la $P_{méca}$ en routine à l'entraînement et en compétition est un bon indicateur au quotidien du niveau de performance du cycliste. C'est dans ce contexte que le PPR trouve son intérêt. Comme présenté dans l'étude I, la méthodologie de détermination du PPR correspond à l'établissement de la relation entre les $P_{méca}$ records et les intervalles de temps équivalents chez le cycliste à partir du suivi longitudinal de la $P_{méca}$ à l'entraînement et en compétition. Le PPR s'assimile donc comme un outil de quantification du niveau de performance du cycliste.

Le fait que le PPR prenne en considération des efforts allant de 1 sec à plusieurs heures est un atout majeur. Toutefois, il entraîne certaines limites. En effet, il caractérise des efforts

maximaux sur un large échantillon de durées contrairement au concept de P_{crit} qui ne comprend que des efforts allant de quelques minutes à moins d'une heure. Mais pour obtenir un PPR valide et fiable, il est nécessaire que l'athlète soit allé au maximum de ses possibilités sur chacune des durées cibles, ce qui rend le processus de détermination relativement long (au minimum une saison). Cette limite dans la méthodologie a fréquemment été soulevée, c'est pourquoi il convient de bien faire la distinction entre une $P_{méca}$ record et une $P_{méca}$ maximale. Il est établit que le PPR concerne essentiellement les $P_{méca}$ records c'est-à-dire les $P_{méca}$ les plus élevées développées par le cycliste, ce qui n'est pas forcément synonyme de $P_{méca}$ maximale.

Comme montré dans l'étude I, le PPR représente une véritable signature biomécanique du potentiel physique d'un cycliste puisqu'il reflète l'expression de l'ensemble de ses qualités physiques. A partir de la classification des zones d'intensité de l'effort de Jones A. M. *et al.* (2009), Francis *et al.* (2010) et Vogt *et al.* (2006), nous avons défini six zones à partir du PPR caractérisant les qualités spécifiques retrouvées en cyclisme (en ajoutant une zone équivalente à une intensité légère) (figure 30):

- la zone 6 traduit les qualités de force – vitesse, communément appelé explosivité dans le jargon cycliste, sur les efforts maximaux inférieurs à 30 sec. La partie haute de cette zone reflète directement la $P_{méca}$ maximale capable d'être directement produite par la voie anaérobie alactique dont la source provient des phosphagènes. Les $P_{méca}$ records dans cette zone traduisent les qualités de sprinter d'un cycliste.
- la zone 5 correspond à la partie haute de la zone d'intensité sévère et correspond aux $P_{méca}$ records entre la PMA et 30 sec, durée généralement où s'exprime la $P_{méca}$ maximale du métabolisme anaérobie lactique. Elle caractérise les efforts maximaux entre 30 sec et environ 4 – 5 min, équivalent à des montées courtes ou des CLM de type prologue. Cette qualité dépend directement du processus anaérobie de la glycolyse.
- la zone 4, initialement délimitée par les $P_{méca}$ records entre 5 et 20 min, coïncide avec la partie basse de la zone d'intensité sévère. Elle traduit les qualités du potentiel maximal aérobio. La limite haute de cette zone correspond à la PMA. Comme démontré à travers l'étude III, la PMA s'avère en moyenne être plus proche de 4 min que de 5 min. D'autre part, la limite basse de cette zone d'intensité sévère correspond à la P_{crit} comme décrit par Jones A. M. *et al.* (2009), qui est très proche également du

deuxième seuil ventilatoire (Dekerle *et al.*, 2003). Cette limite haute a été fixée à la $P_{\text{méca}}$ record sur 20 min. Nous reviendrons sur le concept de la P_{crit} au regard du PPR dans un prochain paragraphe.

- la zone 3, correspondant à une intensité soutenue, s'exprime à travers les $P_{\text{méca}}$ records entre 20 et 60 min. Les $P_{\text{méca}}$ records dans cette zone sont directement en lien avec les qualités spécifiques des grimpeurs ou des rouleurs selon que les niveaux de $P_{\text{méca}}$ sont exprimés en fonction du poids ou de la surface frontale. Ils se caractérisent généralement par des performances maximales sur des montées de cols ou des CLM.
- la zone 2, délimitée par les $P_{\text{méca}}$ records entre 1 et 4 h, correspond à une intensité modérée et reflète la qualité des cyclistes à développer des $P_{\text{méca}}$ élevées sur de longues durées. L'évaluation de l'indice d'endurance aérobie, comme démontré dans l'étude III, complète l'évaluation de la capacité d'endurance aérobie de l'athlète.
- La zone 1, caractérisant une intensité légère, est délimitée par la $P_{\text{méca}}$ record sur 4h et correspond ainsi aux $P_{\text{méca}}$ inférieures.

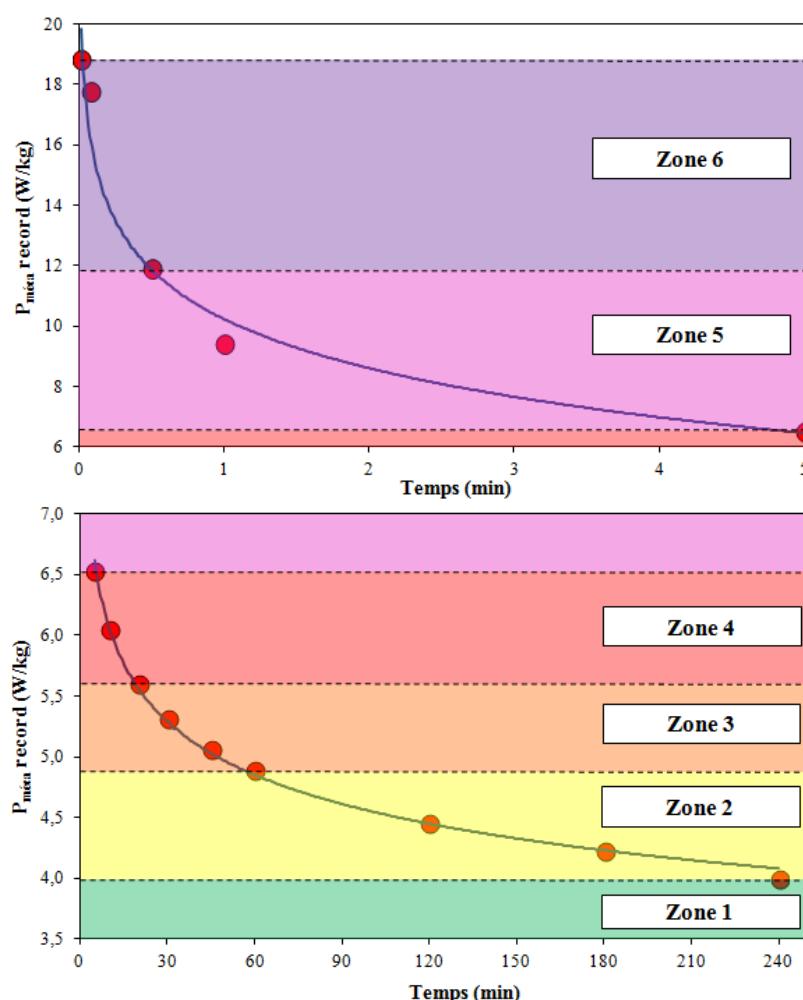


Figure 30 PPR d'un cycliste avec les différentes zones d'intensités délimitées par les $P_{\text{méca}}$ records correspondantes

Le PPR permet ainsi d'évaluer le niveau du potentiel physique du cycliste. Il reflète directement le profil de performance en compétition puisque les niveaux de $P_{méca}$ records dans les différentes zones caractérisent les points forts des grimpeurs, rouleurs, puncheurs et sprinters. De ce fait, il se présente comme un outil majeur dans la détection des jeunes talents puisqu'il permet de cibler les qualités physiques de base. Ainsi, dans le processus de détection des jeunes et dans le recrutement, l'équipe FDJ se base désormais à la fois sur les résultats et sur le profil du PPR du cycliste.

L'étude III a montré que le processus de détermination des zones d'intensité pouvait être appréhendé selon une approche différente. En effet, les zones d'intensités, au delà de refléter les différentes qualités physiques spécifiques au cyclisme, sont également utiles dans le processus d'entraînement, notamment dans le calibrage de l'intensités des séances. Le processus pour obtenir un PPR valide étant relativement long, la détermination de la PMA et de T_{PMA} à partir du PPR ne peuvent s'effectuer qu'après une longue période de monitoring. La démarche judicieuse pour déterminer les zones d'entraînement plus rapidement consisterait à se baser sur la $P_{méca}$ moyenne obtenue sur un test maximal 4 min en montée. L'étude III a montré qu'à partir du PPR de 28 cyclistes, le T_{PMA} moyen était proche de 4 min et que les zones d'intensité pouvaient être dans un premier temps définies avec la relation $\%_{PMA} - \log_t$. Ainsi, en évaluant la PMA à partir de la $P_{méca-4min}$, il est possible de définir les 6 zones suivantes :

- Zone 6 : 190 à 320 % PMA
- Zone 5 : 100 à 190 % PMA
- Zone 4 : 85 à 100 % PMA
- Zone 3 : 75 à 85 % PMA
- Zone 2 : 60 à 75 % PMA
- Zone 1 : < 60 % PMA.

Dans un second temps, le suivi de l'évolution des $P_{méca}$ records permet d'affiner et d'ajuster les différentes zones.

De la même manière, le suivi de la progression des $P_{méca}$ records permet d'affiner la détermination de la PMA, de T_{PMA} et de l'indice d'endurance aérobie du cycliste, à partir de la méthodologie présentée dans l'étude III. Partant du même principe de détermination de l'index d'endurance de Peronnet et Thibault en course à pied (Peronnet et Thibault, 1984 ;

Peronnet *et al.*, 1987 ; Tokmakidis *et al.*, 1987), la relation $P_{méca}$ records – \log_t permet d'exprimer le potentiel aérobio du cycliste, ce qui autorise la détermination d'une PMA et d'un T_{PMA} individuel. Cette méthodologie a pour avantages d'être indépendante d'un protocole de test et de prendre en considération des performances maximales de terrain. Il devient ensuite possible de déterminer un indice de la capacité d'endurance aérobio du cycliste à partir de la relation $\%_{PMA} - \log_t$. Avec le suivi du PPR, l'évaluation du potentiel physique et de ces différents paramètres s'effectuent donc en continu.

Le PPR étant un outil de quantification du niveau de performance, un de ses atouts concerne le suivi de l'évolution du potentiel physique du cycliste dans le temps. Comme le montre l'étude II, le suivi du PPR et des $P_{méca}$ records dans les différentes zones d'intensité autorise la quantification précise de la progression des différentes capacités physiques. L'étude de cas du cycliste de haut niveau, présentée dans l'étude II, apporte un éclairage sur la progression d'un athlète de classe mondiale entre l'adolescence (18 ans) et l'atteinte du plus haut niveau mondial (23 ans) à travers un monitoring de ses performances et paramètres d'entraînement. En effet, le lien entre l'évolution du PPR et celle des indices de la charge d'entraînement, quantifié avec la méthode perceptive de Foster *et al.* (2001), montre un exemple concret de suivi de l'entraînement d'un sportif à partir de méthodes validées scientifiquement.

Toutefois, il convient de bien prendre en considération le fait que les conditions de mesure des $P_{méca}$ records sont dépendantes des conditions dans lesquelles elles ont été réalisées (pacing, drafting, cadence, terrain...). Les études IV et V ont précisément été mises en place afin de mieux comprendre l'influence que peuvent avoir certaines conditions sur la $P_{méca}$ produite par un cycliste, et de ce fait sur les valeurs du PPR. Comme il l'a été observée, la majorité des $P_{méca}$ records à partir de 30 sec concernent des efforts maximaux réalisés en montée. L'étude IV qui a comparé la $P_{méca}$ moyenne sur le plat et en montée a montré que pour un effort de même intensité, la $P_{méca}$ était supérieure en montée de 11% par rapport à celle réalisée sur le plat. Les causes sont multiples mais il est certain que les différences de résistances qui s'opposent à l'avancement contribuent à modifier le couple moteur et la proportion de la $P_{méca}$ utile à l'avancement du système cycliste - vélo. Etant établi que le profil du terrain a une influence sur la valeur de $P_{méca}$ lors d'un effort maximal, la nature du terrain doit être prise en considération pour l'étalonnage des zones d'intensité en vue de la programmations des exercices spécifiques.

Le fait d’alterner les positions assis et danseuse a certainement un impact sur la production de $P_{méca}$ lors de l’effort en montée. En passant de la position assise à celle en danseuse, le bassin s’élève et s’avance pour ne plus être en appui sur la selle. Cette nouvelle posture modifie l’action de la chaîne musculaire des membres inférieurs et supérieurs et donc la transmission des forces sur les pédales (Li et Caldwell, 1998 ; Duc *et al.*, 2008). Hansen *et al.* (2008) ont montré que la position en danseuse permettait d’améliorer les performances maximales sur des efforts allant jusqu’à 4 min. Comme l’étude V le montre, la position en danseuse est génératrice d’une importante quantité d’énergie au niveau du CM. D’importantes différences interindividuelles de $P_{méca-CM}$ entre les cyclistes ont été observées en danseuse, ce qui sous-entend qu’il existe des techniques très différentes d’un cycliste à l’autre. Certains à l’aise, sont fréquemment en danseuse en montée alors que d’autres, moins à l’aise, rouent plus souvent assis. Ainsi, le grimpeur de classe mondiale de l’étude V est capable d’adopter une technique favorisant les transferts entre l’énergie potentielle et l’énergie cinétique, de manière à optimiser l’efficacité mécanique. Le grimpeur, qui alterne fréquemment les positions assis et danseuse en montée, semble donc tirer profit de la position en danseuse pour améliorer ses performances en montée.

Le PPR et les études menées au cours de ce travail de thèse montrent qu’il est délicat d’utiliser les résultats bruts des tests en laboratoire pour l’entraînement sur le terrain. Comme l’étude IV l’a montré, il existe une différence significative de $P_{méca}$ lors d’un effort réalisé sur un ergomètre ou sur le terrain. La $P_{méca}$ en montée est supérieure (8%) à celle sur ergomètre (IndoorTrainer SRM). Toutefois, elle se rapproche de la $P_{méca}$ sur le plat. Il est important de relever que cette différence est dépendante de l’ergomètre utilisé puisque le système de freinage modifie la biomécanique du pédalage (Bertucci *et al.*, 2007). Par conséquent, la P_{crit} et la $P_{méca}$ reliée à des paramètres physiologiques tels que la $\dot{V}O_{2\max}$ ou les seuils ventilatoires, est directement dépendante du protocole et de l’ergomètre utilisé. De plus, la relation $P_{méca}$ records – temps remet également en question le concept de P_{crit} , défini comme une $P_{méca}$ qu’il est possible de soutenir sur une très longue durée. En effet, comme le PPR considère des efforts allant jusqu’à 4 – 5 h, il a permis de montrer que les $P_{méca}$ maximales continuent de décroître au cours du temps. Au final, il apparaît que les concepts et paramètres physiologiques obtenus en laboratoire dans des conditions standardisés n’apportent que très peu d’application sur le terrain. Néanmoins, le suivi de leur évolution dans le temps s’avère être intéressant si les conditions de passation restent identiques pour analyser la progression de l’athlète.

Les applications pratiques issues des différentes études que nous avons conduit ont été nombreuses au sein de l'équipe FDJ depuis 3 ans. Au-delà de l'amélioration de l'évaluation du potentiel physique, l'utilisation du PPR s'est progressivement instaurée comme partie intégrante du processus d'entraînement des cyclistes au quotidien. Une plateforme web a été créée afin de centraliser les informations d'entraînement de l'ensemble des coureurs de l'équipe. Elle a pour but de réaliser 1) le suivi longitudinal des performances maximales de chaque athlète à partir des $P_{méca}$ records, 2) le suivi longitudinal du processus d'entraînement et, 3) la quantification précise des charges d'entraînement. Chaque cycliste possède son compte personnel qu'il met quotidiennement à jour en important les fichiers SRM et en renseignant les indices perceptifs de la séance (CR10, niveaux d'épuisement et de sensations). Ce compte est confidentiel avec un accès réservé uniquement au staff technique (entraîneurs et directeurs sportifs). Ainsi, les données enregistrées par le SRM à l'entraînement et en compétition ($P_{méca}$, fréquence cardiaque, cadence, vitesse, altimétrie, température) sont mises en ligne avant d'être téléchargées puis analysées par les entraîneurs.

Une analyse succincte était réalisée directement sur la plateforme web lors de l'import d'un fichier SRM en calculant (figure 31) :

- les $P_{méca}$ records de la séance sur les différentes durées,
- le pourcentage des $P_{méca}$ records de la séance en fonction des $P_{méca}$ records absolus,
- l'expression du PPR en fonction d'une période défini (par exemple la saison en cours),
- l'expression du PPR en fonction des records absolus.

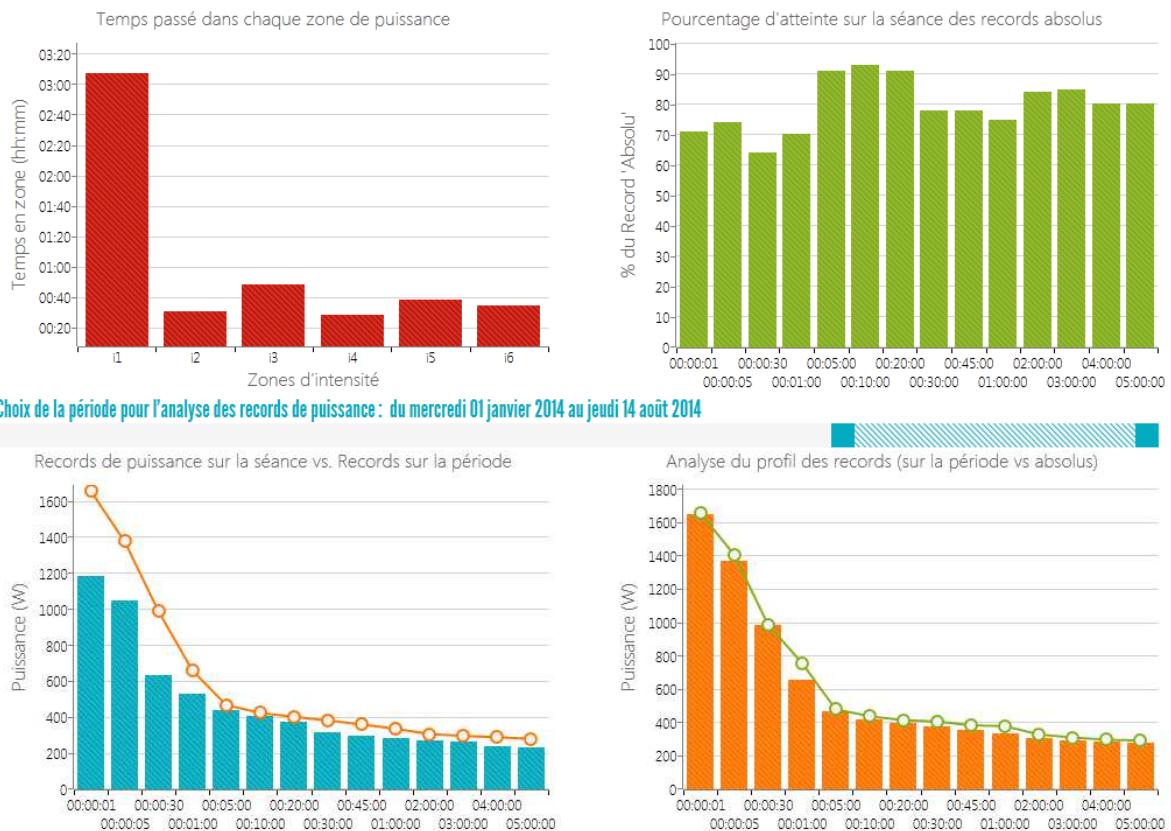


Figure 31 Statistiques d'une séance d'entraînement affichées lors de l'import d'un fichier SRM sur la plateforme web utilisée par les cyclistes de l'équipe FDJ

Avec cette méthode, le cycliste est capable d'interpréter au quotidien la valeur des performances qu'il a réalisé au regard de son potentiel physique maximal. Sur certaines séances nécessitant un engagement mental important, cela peut constituer une source de motivation pour l'athlète. De même, le fait d'améliorer ou de s'approcher d'un record peut être un moyen de mise en confiance à l'approche des objectifs. De leur côté, les entraîneurs actualisent un fichier de suivi des $P_{méca}$ de l'ensemble des performances réalisées à l'entraînement et en compétition (figure 32). A partir de ce répertoire, il devient possible d'établir un classement des $P_{méca}$ records sur chacun des différents intervalles de temps et de suivre l'évolution du PPR au fil des années. Evidemment, l'ajustement des zones d'intensité utile à la calibration de l'intensité des séances d'entraînement se réalise au gré de l'amélioration des $P_{méca}$ records.

Profil de Puissance Record (kW)		13h0	12:34	9:33	6:33	5:22	5:13	5:13	5:07	5:05	5:01	4:38	4:87	4:73	4:57	4:24	4:10	3:91	3:62	3:21	3:12	2:94
		13h0	12:34	9:33	6:33	5:22	5:13	5:13	5:07	5:05	5:01	4:38	4:87	4:73	4:57	4:24	4:10	3:91	3:62	3:21	3:12	2:94
		13h0	12:34	9:33	6:33	5:22	5:13	5:13	5:07	5:05	5:01	4:38	4:87	4:73	4:57	4:24	4:10	3:91	3:62	3:21	3:12	2:94
Durée		00:00:01	00:00:05	00:00:20	00:01:00	00:03:00	00:03:30	00:04:00	00:04:30	00:05:00	00:05:30	00:06:00	00:06:30	00:07:00	00:10:00	00:20:00	00:30:00	00:45:00	01:00:00	02:00:00	03:00:00	04:00:00
PPR 2012		13:11	12:58	8:11	6:39	5:22	5:13	4:97	4:90	4:85	4:79	4:74	4:67	4:64	4:54	4:24	4:08	3:86	3:42	3:16	2:91	2:82
PPR 2013		19:7	15:8	12:1	9:5	7:8	7:7	7:4	7:3	7:2	7:1	7:1	7:0	6:9	6:8	6:3	6:1	5:8	5:4	4:7	4:3	4:2
ENTRAÎNEMENT		13:50	12:94	9:33	6:10	5:20	5:12	5:13	5:07	5:05	5:01	4:58	4:87	4:79	4:57	4:19	4:10	3:91	3:62	3:21	3:12	2:94
COMPÉTITION		13:14	12:94	9:33	5:99	4:92	4:27	4:83	4:77	4:63	4:55	4:50	4:47	4:42	4:18	3:53	3:07	2:98	2:69	2:72	2:59	2:45
DATE		00:00:01	00:00:05	00:00:20	00:01:00	00:03:00	00:03:30	00:04:00	00:04:30	00:05:00	00:05:30	00:06:00	00:06:30	00:07:00	00:10:00	00:20:00	00:30:00	00:45:00	01:00:00	02:00:00	03:00:00	04:00:00
07/02/2013	11:45	9:19	5:73	5:37	5:07	5:04	4:99	4:95	4:93	4:91	4:74	4:62	4:33	4:31	4:13	4:10	3:53	3:27	0	0	0	
20/06/2013	898	854	496	435	433	427	422	422	423	423	413	400	397	391	360	0	0	0	0	0	0	
09/02/2013	12:20	11:67	6:60	5:45	4:78	4:16	4:71	4:70	4:68	4:66	4:66	4:66	4:65	4:64	4:57	4:19	3:95	3:87	3:49	3:00	2:70	
30/06/2013	12:28	11:52	5:95	5:22	4:85	4:77	4:77	4:61	4:54	4:44	4:39	4:36	4:30	4:21	4:21	4:02	3:92	3:30	3:27	2:72	2:46	
19/07/2013	10:56	10:08	5:58	4:77	4:72	4:59	4:59	4:59	4:59	4:54	4:50	4:48	4:46	4:30	4:33	3:87	3:73	3:73	3:42	3:04	2:85	
31/07/2013	961	785	5:85	5:11	4:53	4:10	4:40	4:35	4:32	4:29	4:27	4:24	4:25	4:15	3:99	3:84	3:69	3:31	2:65	2:45	2:43	
14/01/2013	826	704	5:24	4:72	4:36	4:32	4:27	4:26	4:24	4:23	4:19	4:18	4:16	3:95	3:82	3:48	2:98	2:49	2:44	2:44	2:44	
25/08/2013	1033	973	6:40	5:57	4:42	4:43	4:49	4:52	4:46	4:45	4:34	4:25	4:29	4:21	4:21	4:01	3:87	3:32	3:81	2:67	2:22	
06/07/2013	10:52	9:07	4:70	4:54	4:32	4:34	4:31	4:29	4:29	4:25	4:22	4:22	4:21	4:21	4:01	3:80	3:80	3:70	3:62	3:17	2:89	
18/07/2013	11:68	11:10	6:02	5:16	4:60	4:61	4:57	4:55	4:51	4:46	4:45	4:41	4:39	4:31	3:97	3:75	3:70	3:44	3:20	3:12	2:89	
09/06/2013	834	714	4:73	4:40	4:03	4:00	3:98	3:97	3:94	3:90	3:92	3:93	3:86	3:81	3:75	3:40	3:16	2:96	2:74	2:69	2:44	

Figure 32 Exemple de fichier de suivi des $P_{\text{méca}}$ records

Au total, ce travail de thèse montre comment la mesure de la $P_{méca}$ au quotidien accentue le principe d'individualisation du suivi de l'entraînement en cyclisme. Le PPR permet d'affiner la précision dans le processus d'entraînement au niveau de l'évaluation, du monitoring, de la programmation ou encore de la quantification.

Par ailleurs, dans un contexte où le cycliste cherche à se sortir de ses vieux démons et recréabiliser les performances des coureurs, le concept du PPR trouve une certaine légitimité. En effet, il peut permettre aux cyclistes d'exposer l'évolution de leur performances au cours du temps, à l'image du travail mené dans l'étude II. Depuis quelques années, des journalistes, entraîneurs ou scientifiques interprètent dans les médias les $P_{méca}$ produites par les coureurs dans les ascensions de cols à partir de méthodes indirectes afin de spéculer si la performance des cyclistes est crédible ou suspicieuse. Comme l'étude de Millet *et al.* (2013) le montre, ces estimations peuvent être biaisées par de nombreux facteurs notamment ceux influant sur les résistances aérodynamiques (direction et vitesse du vent, drafting...). La publication du PPR par les athlètes pourrait ainsi permettre de donner du crédit aux performances qu'ils réalisent et d'être transparent sur leur progression, en supposant que les $P_{méca}$ données soient justes et mesurées par des capteurs bien calibrés. Certains médias et journalistes ont ainsi déjà évoqué l'utilisation du PPR avec cet objectif (figure 33).

Enfin, le concept du PPR pourrait constituer à l'avenir un puissant outil de mesure préventif et de contrôle dans le temps du potentiel physique du sportif dans le cadre de la lutte contre le dopage. Par exemple, il pourrait permettre de mieux cibler les contrôles antidopage en regard de la progression soudaine d'athlète. Ce travail réalisé dans le cadre du cyclisme pourrait donc inspirer d'autres disciplines sportives dans un proche avenir.

CYCLISME

Le capteur de mensonges

La FDJ a lancé l'idée d'utiliser les capteurs de puissance comme un outil supplémentaire dans la lutte antidopage.

PEN BRON – (Loire Atlantique)

de notre envoyé spécial

ET SI LE CAPTEUR de puissance que l'on voit de plus en plus sur les vélos de pro devient une arme de dissuasion massive pour aider le cyclisme à se débarrasser du dopage ? Rien ne pourra bientôt remplacer les contrôles, mais la technologie de plus en plus sophistiquée qui accompagne aujourd'hui les coureurs pourrait aider les gendarmes à débusquer les dopés.

Depuis quelques années, Fred Grappe, entraîneur de l'équipe FDJ (1), est devenu un inconditionnel du capteur de puissance et ne se lasse pas des enseignements qu'il lui apporte (2). « C'est un élément de travail énorme », dit-il. Aujourd'hui, on peut considérer que plus de 50 % des coureurs dans le peloton utilisent ce système.

Fred Grappe s'en servit pour élaborer une base de données sur chaque coureur. Corrigée et complétée au fil des mois, des tests et des courses, elle lui a permis de dessiner un profil type, qu'il appelle le Profil puissance record (PPR). Il est en effet possible de faire la signature physique de la personne.

« Chaque coureur a son propre profil, explique-t-il. Il faut à peu près six mois de données pour qu'il soit réaliste, mais on peut encore l'affiner avec les années. » Son travail lui a valu une publication dans le journal scientifique américain.

Un complément du passeport biologique

Le capteur de puissance, un SRM (Schoberer Rad Meßtechnik) dans l'équipe FDJ, permet de mesurer la puissance développée par un coureur à chaque tour de pédale, tout comme il se passe en course. En rassemblant toutes ces mesures, l'entraîneur recueille un maximum de données fiables sur la puissance développée sur une durée allant d'une seconde à cinq heures. Au fil des mois ou des ans, la courbe peut témoigner des progrès des coureurs. « Mon profil de puissance va progresser je crois tous les jours », explique Jérémie Roy, le coureur de la FDJ. « Il me permet de me situer physiquement. » Mais il peut aussi trahir une transgression des règles. « Par exemple : si le coureur réalise une performance nettement supérieure à ses records enregistrés, c'est probablement qu'il a triché. »

« Une variation trop importante d'un profil bien défini pourrait interpréter

le », dit Fred Grappe de façon plus diplomatique. Il est persuadé que son travail pourrait devenir un allié du passeport biologique, qui fonctionne de la même manière, mais pour les valeurs hématologiques. « Ce genre de test, coupé au passage, peut également devenir un excellent outil de travail pour la lutte antidopage, souligne-t-il. En plus, mis à part le prix du capteur (de 1 000 à 3 500 euros), ce n'est pas cher. Le capteur de puissance est un outil de mesure sensible mais fiable. Il faut juste s'assurer de temps en temps du bon état d'emploi du système. » Les systèmes des contrôles inopinés des capteurs comme on organise aujourd'hui des contrôles inopinés sanguins ou urinaires. Ensuite, il faudrait croiser les données du passeport biologique avec le Profil puissance record. Malheureusement, aucune étude comparative n'a été faite jusqu'à présent. »

Fred Grappe a rencontré Julian Pinot, frère de Thibaut et auteur d'un mémoire sur une nouvelle méthode d'analyse du potentiel physique du cycliste, reste persuadé qu'il est sur la bonne voie et que si les contrôles sanguins et urinaires sont indispensables, sa méthode pourrait s'imposer.

Il y a deux ans, il a également commencé à débattre avec les scientifiques au moment de la mise en place du passeport biologique. « C'était une rencontre entre universitaires, explique-t-il. Mais c'est bien la preuve que ces chercheurs ont trouvé un certain intérêt à ce travail. »

La lutte antidopage va gagnerait en efficacité et le système présenterait aussi l'avantage de responsabiliser davantage les équipes.

« Aujourd'hui, avec un tel profil, les managers ne peuvent plus dire qu'ils ne savaient pas forcément si leurs coureurs sont propres ou non », insiste Fred Grappe. En adoptant un tel système de contrôle, on obligerait aussi les équipes à passer des déclarations de bonnes intentions à la mise en pratique de leurs résolutions. Hier, l'équipe Androni-Venezuela a appris que son soutien à l'initiative de la FDJ. Un nouvel élan ?

MANUEL MARTINEZ

(1) Il est aussi maître de conférences en biomécanique et physiologie de l'exercice musculaire à l'université de Besançon.

(2) Julian Pinot, frère de Thibaut et lui-même entraîneur, prépare une thèse de doctorat sur le PPR.

Le capteur de puissance, comment ça marche ?



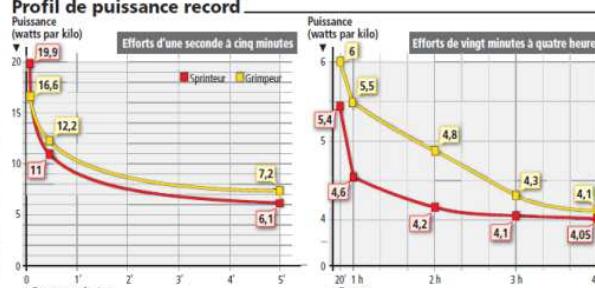
L : longueur de la manivelle (longueur du bras sur lequel repose la pédale).
F : force exercée sur la pédale.
C : cadence de pédale (tour/minute).

LE CALCUL DE LA FORCE EFFICACE

Lorsque le coureur appuie sur ses pédales (ici contre Naer Bubhani), la pression exerce une déformation. Le capteur enregistre cette déformation. Il calcule ce qu'il doit donner comme la force efficace du coureur. En fonction de la fréquence des pédales et de la fréquence de pédale enregistrée (le nombre de tours de pédales effectués par le coureur), le capteur connaît cette déformation en une puissance exprimée en watts.

Les pros s'en servent à l'entraînement. Ils suivent des plans préparés par leur entraîneur qui leur imposent de maintenir un nombre précis de watts pendant une certaine durée sur un certain type de terrain, par exemple. Ils s'en servent également dans les contre-la-montre, notamment pour déterminer à quel vitesse et à quel rythme il faut faire pour ne pas se mettre trop rapidement dans le rouge. Mais ils utilisent aussi le capteur de puissance dans des situations de course. Lors du dernier Tour de France, Bradley Wiggins a expliqué que, s'il n'avait pas accéléré pour répondre aux attaques de Vincenzo Nibali dans les cols, il n'aurait pas pu garder son capteur en place qu'il évidait déjà à l'heure du plateau. C'est pourquoi il a suivi donc que l'Italien ne pouvait pas maintenir cet effort très longtemps. Donc le capteur peut aussi avoir des répercussions tactiques sur la course.

Profil de puissance record



VOCILES PPR DE DEUX COUREURS

Chaque profil de puissance atteint par ces coureurs lors d'efforts allant d'une seconde à une heure. Le premier coureur (courbe rouge) est un sprinteur, le second (courbe jaune), un grimpeur.

Le premier montre le calcul de ce profil sur des efforts allant de une seconde à cinq minutes. Le second, sur des efforts allant de vingt minutes à quatre heures.

Le sprinteur, au physique plus massif, plus musclé, est aussi plus expérimenté. Son profil de puissance (l'effort de fond) est bien plus élevé (15-18 watts par kilo) que celui du grimpeur (16-17 watts par kilo). Mais dès que l'effort atteint les trente secondes, la courbe du grimpeur passe au-dessus de celle du sprinteur. Au bout de quatre heures, en revanche, on se situe dans les efforts d'endurance et les courbes se rapprochent. « C'est un peu comme si on mesurait les performances d'un athlète sur un 100 m, un 400 m, un 1 500 m, un 10 000 m et jusqu'au marathon », explique Fred Grappe.

Le déplacement temporel de ces variations de puissance correspond une allure constante de 400 mètres par minute, soit 6 km/h. « C'est surtout des efforts compris entre cinq minutes et une heure qui seraient révélateurs », ajoute Fred Grappe. Autrement dit, on pourrait désormais suffrir les excès de vitesse sur des efforts de cette durée, comme un contre-la-montre ou une ascension de col... Référence : Fred Grappe, Puissance et performance en cyclisme, éditions De Boeck, 2012.

L'AMA cherche un outil universel

L'AGENCE MONDIALE antidopage (AMA) pourra-t-elle intégrer les données individuelles recueillies par le biais d'un indicateur de performance et les constigner dans le passeport des athlètes de toute discipline de leur choix ?

« Si le principe est oui », selon l'un des responsables de l'agence, qui s'intéresse depuis toujours à cette problématique.

« L'introduction d'indicateurs de performance tels que les capteurs de puissance ont déjà fait l'objet de discussions à l'AMA, dans le cadre de réflexions plus larges sur les profils de performances des sportifs.

Les données quantitatives brutes peuvent être utiles dans l'identification de personnes dopantes, et des variations imprévues ou étranges de la performance pourraient être prises en compte pour cibler certains sports dans le cadre de contrôles imprévisibles intelligents. »

« Cette information supplémentaire pourrait potentiellement faire partie du processus d'évaluation dans le cadre du passeport biologique de l'athlète (PBA), mais, selon nous, la performance de ce capteur de puissance est actuellement limitée à un nombre trop restreint de sports. Bien que l'AMA continue d'investiguer dans ce domaine, elle ne prévoit donc pas d'intégrer de statistiques sur les performances au PBA dans un futur proche. » D. R.

Figure 33 Article du journal L'Equipe du 14 décembre 2012 sur l'intérêt du PPR

CONCLUSION GENERALE ET PERSPECTIVES

Les études conduites au cours de ce travail de thèse ont montré que la $P_{méca}$ était une variable centrale dans le processus d'optimisation de la performance en cyclisme. Nos recherches ont porté sur deux axes principaux d'analyse de la performance : 1) l'évaluation et le monitoring du potentiel physique avec pour but l'amélioration du suivi de l'entraînement et 2) l'optimisation de l'interface homme – machine à partir du développement de nouveaux composants matériels et équipements. L'ensemble des résultats obtenus montre que la capacité de performance du cycliste peut être évaluée à partir de la mesure de la $P_{méca}$ en analysant :

- ses différentes qualités physiques, exprimées par le PPR à partir de la relation $P_{méca}$ record – temps ;
- sa progression longitudinale (à travers les années) quantifiée à partir de l'évolution du PPR en réponse au processus de suivi de l'entraînement ;
- les conditions de locomotion (plat, montée, laboratoire) qui ont une influence directe sur le niveau de $P_{méca}$ produit ;
- la technique utilisée lors de l'exercice en danseuse à travers les transferts d'énergie qui ont lieu au niveau du centre de masse ;
- le matériel utilisé qui est directement en lien avec le niveau des résistances qui s'opposent à l'avancement.

L'analyse de la $P_{méca}$ à l'intersection de ces différentes sphères liées à la performance a permis d'optimiser de manière rationnelle le niveau de performance d'ensemble des cyclistes de l'équipe FDJ.

Ce travail de thèse est novateur dans le domaine de l'optimisation de la performance sportive puisqu'il a été entièrement conduit au sein d'une équipe cycliste professionnelle à la faveur de la création d'un département R&D au sein de l'équipe. Lors de ces trois années, l'ensemble du staff technique et des coureurs a complètement adhéré aux activités conduites par ce département. Pour preuve, les résultats obtenus au fil des trois saisons par les cyclistes de l'équipe FDJ ont été en constante progression en reflétant la nouvelle dimension de l'équipe acquise sur le plan international avec des jeunes leaders talentueux. Il paraît donc aujourd'hui indispensable de poursuivre le travail entrepris au cours de cette thèse, notamment dans un contexte compétitif avec une concurrence accrue et perpétuelle entre les équipes World Tour. Les apprentissages tirés de chacune des études qui ont été conduites, même s'ils n'ont pas

toujours aboutis à des résultats positifs, nous ont permis d'améliorer de manière significative nos connaissances et notre approche expérimentale, notamment dans l'évaluation de la traînée aérodynamique. Le travail sur l'amélioration du matériel et des équipements, en relation avec les partenaires, devra être poursuivi. Au-delà des aspects aérodynamiques, nos recherches vont également être conduites sur d'autres paramètres comme : la résistance au roulement (pneumatiques), la rigidité (cadres et roues), le pilotage (pneumatiques, cadres et roues), le confort (cadres, roues et pneumatiques) ou encore les frictions mécaniques (lubrifiant et roulements). Les prochaines études devront offrir la possibilité de choisir les meilleurs compromis en terme de matériels et d'équipements en fonction des conditions de pratiques rencontrées par les cyclistes de l'équipe FDJ. Enfin, les recherches qui ont été portées sur l'évaluation du potentiel physique et sur l'analyse de la technique en danseuse seront également approfondies car nous savons pertinemment que certains mécanismes sous-jacents doivent être encore étudiés.

Le but ultime fixé par l'équipe FDJ pour les prochaines années est d'améliorer la capacité de performance de l'ensemble de ses coureurs et de ses leaders en continuant à travailler d'arrache pieds sur l'interface entre le cycliste et sa machine en mettant en complète relation les sphères scientifique et pratiques et en accentuant le développement de chacune d'elles.

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ANNEXES

1. Co-auteur d'un article publié dans la revue internationale Journal of Science and Cycling.

J Sci Cycling. Vol. 2(2), 49-56

RESEARCH ARTICLE

Open Access

Effects of recovery using contrast water therapy or compression stockings on subsequent 5-min cycling performance

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Abstract

Many researchers have investigated the effectiveness of contrast water therapy (CWT) or compression stockings (CS) during recovery, using subsequent performance as the principal outcome measure. However, data in the literature are contradictory, mainly because of the methodology used. Purpose: Based on well-controlled performance measures, this study aimed to compare the effects of CWT, CS or passive recovery (PR) on subsequent performance. Methods: After inclusion based on reproducibility criteria (intra-participant variability in performance test lower than the expected differences between the recovery interventions, i.e. 1.5%), 12 competitive male cyclists (peak power output: 5.0 ± 0.2 W/kg; cycling practice: 4.9 ± 0.4 times/week; intra-participant variability: $1.2 \pm 0.2\%$) came to the laboratory three times in a random crossover design. Each time visit, they performed a tiring exercise on a cycle ergometer, followed by a 5-min performance test during which the mean power output was recorded, separated by a 15-min recovery period during which a 12-min PR, CWT (1:2 (cold: 10–12°C to warm: 36–38°C) min ratio) or CS (~20 mmHg) was implemented. Results: Compared with PR (353.8 ± 13.1 W), performance was significantly higher after CWT (368.1 ± 12.3 W) and CS (360.5 ± 14.8 W). Moreover, performance was significantly higher after CWT than after CS. Conclusion: Athletes can use this information as a way of improving their performance in competition format using repeated high-intensity exercises in a short period of time, such as in mountain bike, track or BMX races. Moreover, these data reinforce interest for researchers to consider performance tests with high test-retest reproducibility, especially when small but real benefits are expected.

Keywords: recovery methods, water immersion, elastic compression, exercise reproducibility

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Introduction

In recent years, recovery interventions between repeated bouts of exhaustive exercise have become a major focus in the field of sports science (Barnett 2006). In order to remain efficient at a high level for subsequent performances, it is of fundamental importance to put the interspersed recovery period to good use. It is the case in competition format using

subsequent bouts of high-intensity exercise in a short period of time (series and final). In cycling, races from many disciplines take place in the form of tournament with several phases competed on a single day. Some races of mountain bike (cross-country eliminator), track (pursuits, points race, scratch, omnium...) and BMX consist in sequence of series, qualifying rounds and finals with short recovery times.

Nowadays, athletes therefore use a wide variety of passive strategies to accelerate short-term recovery. These passive strategies present the advantage to result in a greater amount of muscle glycogen resynthesis than active strategies (as active recovery) over the same duration (Choi et al. 1994). Compression garments and water immersion (including hot, cold and contrast water) are examples of passive strategies often studied and reviewed (Barnett 2006). Hot water immersion immersion (<15°C) is assumed to be more beneficial in treatment of exercise-induced muscle damage following unaccustomed or eccentric (Bleakley et al. 2012) than between repeated high-intensity exercises (Parouty et al. 2010). Conversely, there is a growing body of evidence to support the use of compression stocking (CS) and contrast water therapy (CWT: alternation of brief exposures of contrasted temperatures: $\leq 15^\circ\text{C}$ to $\geq 35^\circ\text{C}$) between repeated high-intensity exercises (Chatard et al. 2004; Crampton et al.



2011; Versey et al. 2011). These recovery strategies are thought to increase blood flow and venous return through application of pressure to the limbs (Ménétier et al. 2013). The promotion of blood circulation is suggested to be an effective method in removing the metabolic waste products that accumulate during this kind of exercise and, therefore, enhance recovery (Barnett 2006). Furthermore, the external pressure created by the water or the compression garments and the cold application may improve perceptions of recovery or 'wellbeing' reducing muscle soreness (Washington et al. 2000; Weiss and Duffy 1999). However to date, no study has yet compared CS and CWT directly, between exercise bouts where a short turnaround time (15-30 min) is required. This comparison could provide direction for athletic trainers, as a way of potentially improving the recovery of their athletes during subsequent bouts of exercise. Results of research into the effectiveness of CS (Chatard et al. 2004; Ménétier et al. 2011) and CWT (Crampton et al. 2011; Stanley et al. 2012) using subsequent performance as the principal outcome measure are contradictory, whereas this outcome is of major importance. Compared with passive recovery (PR), only one study has reported significant effects of CS on subsequent performance (Chatard et al. 2004), while many studies have reported no change (Ali et al. 2007; Ménétier et al. 2011; Scanlan et al. 2008). With regard to CWT, some studies have reported significant positive effects on subsequent performance (Crampton et al. 2011; Versey et al. 2011). Beyond differences in study design (involving different recovery period (Crampton et al. 2011; Stanley et al. 2012)), studied population (untrained or elite athletes (Chatard et al. 2004; Ménétier et al. 2011)) or in application modalities of the recovery intervention (Crampton et al. 2011; Stanley et al. 2012); the main reason that could

interpretation of the results. When small benefits are expected (~2% after CS (Chatard et al. 2004) and ~3-8% after CWT (Crampton et al. 2011; Versey et al. 2011)) it seems warranted that more controlled studies are needed to ensure that differences are real. Thus, the intra-participant variability within repeated performance tests must be a key consideration for making pragmatic assumptions about the effectiveness of recovery interventions and must be lower than the expected effects of those (Hopkins et al. 2001).

Therefore, the aim of our study was to compare with PR, the effects on subsequent performance of CWT and CS. We intended to detect small but real benefits, using a sensitive methodology based on a well-controlled performance test with high test-retest reproducibility. Our hypothesis was that CWT and CS would significantly increase the cycling performance after a previous fatiguing exercise. Although no study has yet compared them directly, in light of results in the literature (Crampton et al. 2011; Ménétier et al. 2011; Versey et al. 2011), we also hypothesized that this improvement would be greater after CWT. To provide more complete information for athletic trainers, we also compared the effects of CWT and CS on recovery parameters usually studied in the literature, such as blood lactate concentrations and muscular soreness perceptions.

Materials and methods

Design

We used a 5-min cycle ergometer test, during which the mean power output was registered (Chatard et al. 2004), to assess the effects of CWT and CS on the subsequent performance. This kind of exercise was chosen because of its strong reproducibility (Chatard et al. 2004). Based on the literature, the expected improvement in this performance test after CWT and

explain the contradictory results may be linked to the test-retest reproducibility of the performance test (Hopkins 2004). Indeed, the variability, expressed as a coefficient of variation (Hopkins et al. 2001), is often greater than the expected benefits of the studied recovery interventions and may confuse the

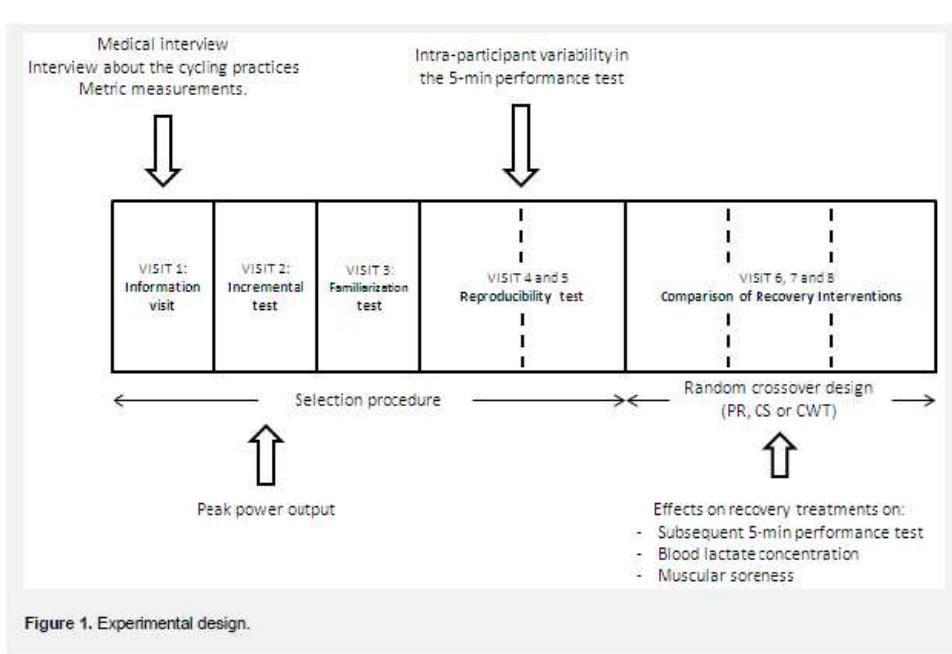


Figure 1. Experimental design.

Ménétier et al. (2013). Effects of recovery using contrast water therapy or compression stockings on subsequent 5-min cycling performance. *Journal of Science and Cycling*, 2(2): 49-56

CS was 1.5% or more (Chatard et al. 2004; Crampton et al. 2011; Versey et al. 2011). Therefore participants able to reproduce a 5-min cycle ergometer test with a variability <1.5% were recruited (Hopkins et al. 2001). We calculated that 12 participants would be sufficient to show a difference of 1.5% or more between interventions in the cycle ergometer performance, with a beta risk of 10% and an alpha risk of 5%.

Our protocol comprised two parts:

-A selection procedure (5 visits) to recruit participants able to reproduce the 5-min maximal cycling exercise with a variability <1.5%.

-3 other visits in a random crossover design to compare the effects of the recovery interventions on the subsequent performance. These visits were designed to simulate a competition format using subsequent bouts of high-intensity exercise in a short period of time (series and final). Each time visit, the participants performed a tiring exercise on a cycle ergometer followed by the 5-min performance test, separated by a 15-min recovery period during which PR, CWT or CS was implemented.

Participants

After verbal and written explanation, volunteer participants underwent the selection procedure for potential inclusion (visits 1 to 5). The inclusion criteria were: (a) competitive male cyclists recruited in the regional cycling team (with an experience in competitive cycling of more than 5 years); (b) peak power output comprised between 4.5 and 6 W/Kg and cycling training between 4 and 6 times sessions/week (6 and 12 hours/week); elaborate on (c) context of competitive period (to minimize the possible training or habituation effect) (Sassi et al. 2008); (d) ability to reproduce the performance test used to compare the recovery interventions with a variability <1.5%, since as, based on the literature the expected improvement after CWT and CS was 1.5% or more (Chatard et al. 2004); (e) not familiarized with CS and CWT; (f) no history of systemic disease; and (f) no ongoing

medication.

The first 12 competitive male cyclists (mean \pm SEM age: 20.7 ± 0.6 years (19.0-23.0); height: 179.4 ± 1.4 cm (172.0-188.0); weight: 71.8 ± 1.6 kg (66.4-88.2); experience in cycling: 6.25 ± 0.4 (5.0-9.0); peak power output: 5.0 ± 0.2 W (4.5-6.0); cycling practice: 4.9 ± 0.4 times/week (4.0-6.0) (8.7 ± 0.7 hours/week (6.0-12.0)); intra-participant variability: $1.2 \pm 0.2\%$ (0.5-1.5)) who met the inclusion criteria were included, and performed the study protocol of the comparison of recovery interventions (visits 6 to 8). The results of the selection procedure are presented in Table 1.

Participants were provided verbal and written information of experimental procedures and signed informed consent statements and medical history forms before study initiation. The study protocol was approved by the local ethics committee, and the study was in accordance with the Declaration of Helsinki (Harris and Atkinson 2009).

Testing Conditions

This study was performed in spring (context of competitive period) (Sassi et al. 2008). Participants were requested to abstain from competition and maintain constant life habits (nutrition, sleep, etc.). Only light training was tolerated.

Laboratory visits for the study purposes were performed at the same time of the day (between 6:00 and 9:00 PM) and in similar environmental conditions (temperature: $\sim 21^\circ\text{C}$, humidity: $\sim 30\%$), at intervals of 48 to 96 hours. Food was prohibited during the visits, but although participants had to drink 50 cl of water each time.

Selection Procedures

The selection procedure comprised five visits to the laboratory (visits 1, 2, 3, 4 and 5) to verify the inclusion criteria, as follows:

Visit 1 – Information Visit: The participants received verbal and written explanations before signing an informed consent document. Participants then had a medical interview; an interview about their cycling

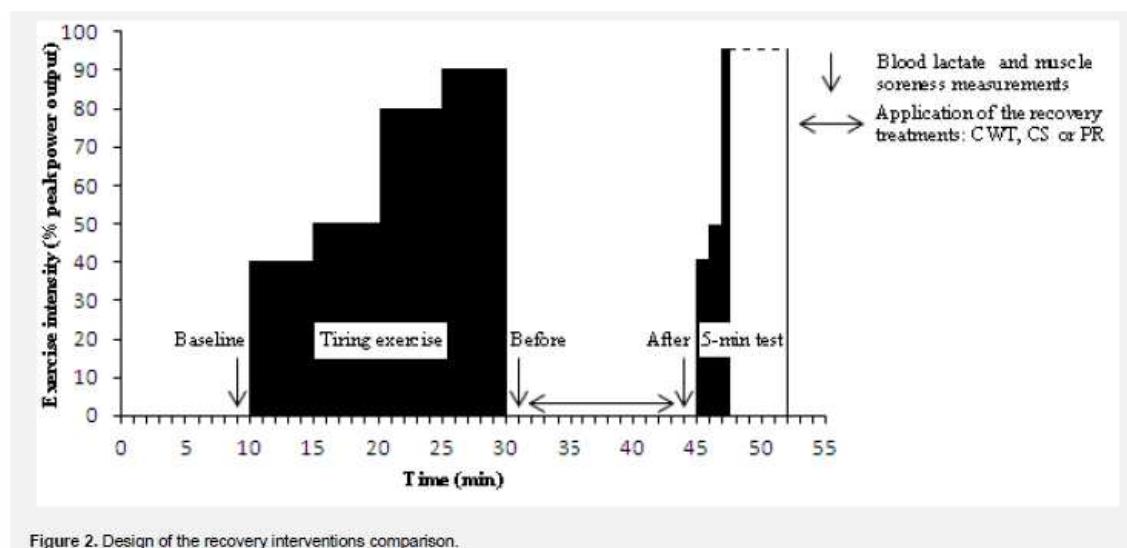


Figure 2. Design of the recovery interventions comparison.

practices; and metric measurements.

Visit 2 - Incremental Test: The second visit included an incremental test to exhaustion (start: 100 W, increments: 30 W/2 min) on a cycle ergometer (Wattbike, Nottingham, UK). Peak power output was recorded (Faria et al. 2005). Heart rate was recorded with a heart rate monitor (Suunto t6, Suunto, Oy, Finland). Peak heart rate during the incremental test was considered as the average value observed over the 15 sec period where heart rate was highest. Difficulty and exertion perceived by the participants at the end of the exercise were quantified using the CR10 Borg-scale (Borg et al. 1985). The state of exhaustion was validated by the achievement of the theoretical maximal heart rate (220 – age) and the maximal rating of perceived exertion (CR10 = 10).

Visit 3 – Familiarization Test: Participants underwent a familiarization trial in laboratory (same exercise bout proposed in visits 4 and 5) in order to get used to the experiment and to eliminate the training effect (Abbiss et al. 2008).

Visits 4 and 5 - Reproducibility Test: The participants' ability to reproduce the exercise used to compare the recovery interventions was tested. The two visits to establish the reproducibility comprised the same 5-min exercise bout on cycle ergometer preceded by a standardized warm-up (5 min at 40%, 5 min at 50% and 5 min at 60% of peak power output). Braking force was constant during the exercise and was calculated to obtain a pedaling frequency around 90–100 rpm. The mean power output developed by the participant during the trial was registered throughout via an interface between the cycloergometer and the computer and expressed in watts for 5 min. The only way to increase or reduce the power was to increase or reduce the pedaling frequency. During the protocol, participants were not informed about any performance results. In order to guide the participants, intensity was fixed at 95% of peak power output during the first 30 sec. After that, the time countdown was the only information communicated to the participants. Peak heart rate during reproducibility test was considered as the average value observed over the 15 sec period where heart rate was highest. Difficulty and exertion perceived by the participants at the end of the exercise were quantified to verify that the fatigue criteria were identical from one visit to the next.

Comparison of Recovery Interventions

Participants who were included in the study performed the laboratory protocol comprising three test visits (visits 6, 7 and 8), in a randomized order, to compare the three recovery interventions.

Visits 6, 7 and 8: These visits included 10 min at rest, a 10-min warm up (5 min each at 30% and 40% of peak power output) followed by a tiring exercise (5 min each at 80% and 90% of peak power output), then a 15-min recovery period during which one of the three 12-min recovery interventions was implemented, and finally a standardized warm up (40 sec each at 40%, 50% and 60% of peak power output) followed by a 5-min test on

cycle ergometer (Figure 1). During the 5-min test, the participants had to produce the greatest mean possible power output for the whole 5-min exercise. Braking force, pedaling frequency modalities and any other procedures were the same that as during the reproducibility test. The mean power output sustained by the participants over the 5-min test was registered to compare the performances achieved after each recovery intervention (Chatard et al. 2004). Blood samples (5 µL) were taken at the earlobe before tiring exercise (baseline), and before and after the application of the recovery interventions in a sitting position. The blood samples were immediately analyzed with the Lactate Pro device (Arkray, Kyoto, Japan) to measure blood lactate concentrations. The average value observed over the 15-sec period where heart rate was highest during both tiring exercise and 5-min test and difficulty and exertion as perceived by the participants at the end of the both exercises were quantified to assess fatigue criteria. A visual analogue pain scale (1-10) was used to assess muscular soreness whereby participants were required to rank their perception of soreness on a scale, with 0 being 'normal' and 10 being 'extremely sore' (Vaile et al. 2008). Pain ranking was reported at baseline and before and after the application of the recovery interventions.

Recovery Interventions

Recovery period included 1.5 min in a sitting position before and after the 12 min of recovery interventions, which consisted in resting in vertical position with garments used for cycling. For PR, the participants wore garments used for cycling only. For CS, the participants also wore full leg compression stockings from the ankle to the groin (Full Leg, Compressport, Geneva, Switzerland). According to the size chart provided by the manufacturer, the pressure applied by the CS is estimated to be 14, 27, and 15 mmHg at the thigh, calf and ankle respectively. For CWT, participants underwent 4 cycles of 3 minutes each, comprising immersion to the top of the thigh (~75 cm of water for a height of 180 cm) in a cold bath (10–12°C) for 1 min, followed by 2 min in a hot bath (36–38°C) with a 5-s changeover (Wilcock et al. 2006). With ~60 cm of water above the ankle, ~45 cm above the calf and ~15 cm above the thigh, the mean pressure applied by CWT is ~45 mmHg at the ankle, ~34 mmHg at the calf and 11 mmHg at the thigh.

Statistical Analyses

Statistical analyses were performed using SigmaStat for Windows 3.5 (Systat Software Inc., San Jose, CA, USA). Data are presented as mean ± standard error of the mean (SEM). A *p*-value < 0.05 was considered statistically significant. Normality was tested using the Kolmogorov-Smirnov Test. Appropriate parametric or non-parametric tests were used. To assess the reproducibility of the participants (visits 4 and 5), mean power output and peak heart rate were analyzed using the paired Student *t*-Test and CR10 was analyzed using the Wilcoxon Signed Rank Test. To check that the state of exhaustion achieved during tiring exercise was

Ménétier et al. (2013). Effects of recovery using contrast water therapy or compression stockings on subsequent 5-min cycling performance. *Journal of Science and Cycling*, 2(2): 49-56

identical between visits 6, 7 and 8, heart rate and CR10 were analyzed using One Way Repeated Measures ANOVA. To assess the effects of the recovery interventions, performance in 5-min test was also analyzed using One Way Repeated Measures ANOVA. Heart rate and CR10 during 5-min test were analyzed using Friedman's Repeated Measures ANOVA on Ranks. Blood lactate concentrations and muscular soreness data were analyzed using Two Way Repeated Measures ANOVA. Fisher's LSD Test was used for pairwise comparisons. Intra-participant variability is defined as the ratio of the standard deviation to the mean, which is known as the absolute value of the coefficient of variation, expressed as a percentage. We assessed the reliability of these data with the intraclass correlation coefficient: using a 2-way random effects model with single-measure reliability in which variance over the repeated session is considered. The ICC indicates the error in measurements as a proportion of the total variance in scores. As a general rule, we considered an intraclass correlation coefficient over 0.90 as high, between 0.80 and 0.90 as moderate, and below 0.80 as insufficient.

Results

Performance: After CWT ($+4.1 \pm 0.7\%$, $p < 0.001$) and CS ($+1.8 \pm 1.0\%$, $p < 0.05$), 5-min test performance (mean power output sustained over the 5-min) was higher than after PR. Moreover, performance was greater after CWT than after CS ($+2.2 \pm 0.8\%$; $p < 0.05$) (Figure 2A).

Blood Lactate Concentrations: No significant difference was observed in blood lactate concentrations before the recovery interventions. At baseline, blood lactate concentrations were $1.4 \pm 0.2 \text{ mmol.L}^{-1}$, $1.2 \pm 0.1 \text{ mmol.L}^{-1}$ and $1.3 \pm 0.1 \text{ mmol.L}^{-1}$ and before the application of the recovery interventions, blood lactate concentrations were $13.0 \pm 0.8 \text{ mmol.L}^{-1}$, $12.8 \pm 1.0 \text{ mmol.L}^{-1}$ and $12.3 \pm 1.0 \text{ mmol.L}^{-1}$ for PR, CS and CWT conditions respectively. After CWT ($5.7 \pm 1.0 \text{ mmol.L}^{-1}$, $p < 0.001$) and CS ($7.3 \pm 1.2 \text{ mmol.L}^{-1}$, $p < 0.05$), blood lactate concentrations were lower than after PR; and ($8.4 \pm 1.0 \text{ mmol.L}^{-1}$). Moreover, blood lactate concentrations were lower after CWT than after CS ($p < 0.05$) (Figure 2B).

Perceived Muscular Soreness: No significant difference was observed in muscular soreness before the recovery interventions. At baseline, muscular soreness were 0.0 au for the three visits and before the application of the

recovery interventions, muscular soreness were $7.0 \pm 0.3 \text{ au}$, $6.5 \pm 0.3 \text{ au}$ and $6.5 \pm 0.3 \text{ au}$ for PR, CS and

Table 1. Incremental and reproducibility tests results ($n = 12$). * In Mean Power Output.

Visit 2: Incremental Test	
Peak power output (W.kg^{-1})	5.0 ± 0.2
Peak heart rate (beats. min^{-1})	193.1 ± 2.7
CR10 (au)	10.0 ± 0.0
Reproducibility Test	
Visit 4:	
Mean Power Output (W)	360.1 ± 11.0
Peak heart rate (beats. min^{-1})	193.1 ± 2.8
CR10 (au)	10.0 ± 0.0
Visit 5:	
Mean Power Output (W)	362.2 ± 10.9
Peak heart rate (beats. min^{-1})	192.4 ± 2.6
CR10 (au)	10.0 ± 0.0
Intra-participant variability*	$1.2 \pm 0.2\% (0.5-1.5)$
Intraclass correlation coefficient*	0.99

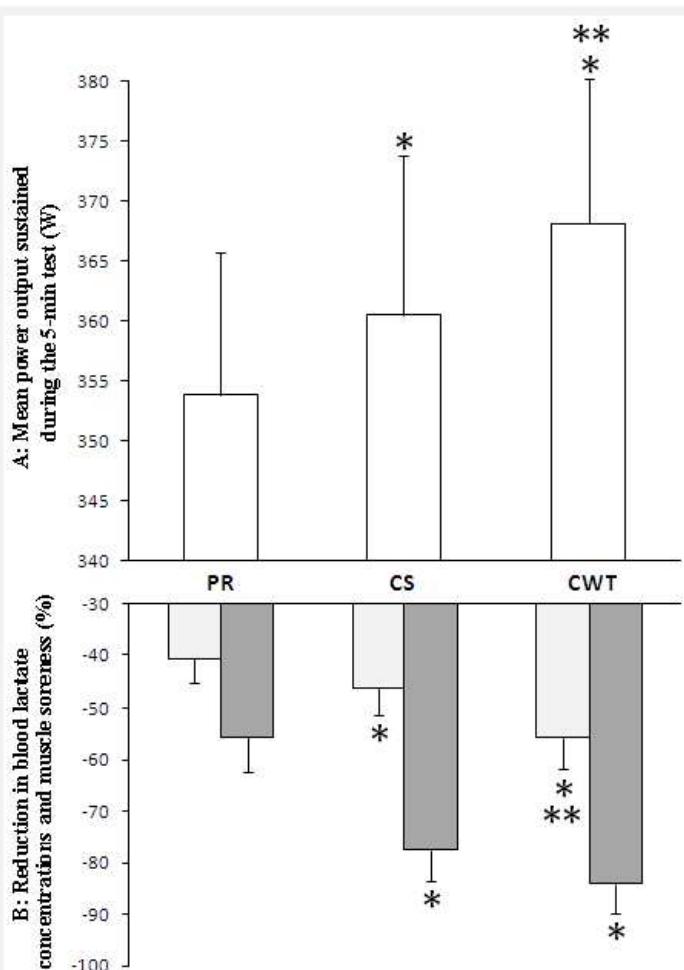


Figure 2. panel A: mean power output sustained over the 5-min test and panel B: reduction in ■ blood lactate concentrations and □ muscular soreness (%)
(Corresponding to: [(after the application of the recovery interventions data - before the application of the recovery interventions data) / before the application of the recovery interventions data * 100]) during the three visits of the recovery interventions comparison. *: Indicates a significant difference between CWT or CS and PR. **: Indicates a significant difference between CWT and CS.

CWT conditions respectively. After CWT (1.1 ± 0.4 au, $p < 0.001$) and CS (1.6 ± 0.4 au, $p < 0.001$), muscular soreness were lower than after PR (3.2 ± 0.5 au). Moreover, muscular soreness were lower after CWT than after CS without attaining the significance threshold ($-29.2 \pm 12.2\%$; $p = 0.08$) (Figure 2B).

Heart Rate: Heart rates during tiring exercise (184.1 ± 1.6 beats.min $^{-1}$, 183.6 ± 2.2 beats.min $^{-1}$ and 182.1 ± 2.3 beats.min $^{-1}$ for PR, CS and CWT conditions respectively) and 5-min test (188.6 ± 2.3 beats.min $^{-1}$, 189.4 ± 1.9 beats.min $^{-1}$ and 190.2 ± 2.0 beats.min $^{-1}$ for PR, CS and CWT conditions respectively) were not statistically different for the three visits.

CR10: CR10 during tiring exercise (9.1 ± 0.3 au, 8.6 ± 0.2 au and 8.7 ± 0.2 au for PR, CS and CWT conditions respectively) and 5-min test (10.0 ± 0.0 au for the three visits) were not statistically different for the three visits.

Discussion

The present study aimed at testing the hypothesis that CWT and CS would significantly increase the subsequent cycling performance. We also hypothesized that this improvement would be greater after CWT. Contrary to most of the previous studies; this was done with a study design based on well controlled performance test with high test-retest reproducibility. Our results are in accordance with previous studies and confirm that CWT (Crampton et al. 2011; Versey et al. 2011) and CS (Chatard et al. 2004) significantly increased subsequent performance compared with PR, by increasing the mean power output sustained over the 5-min test by 14.2 ± 2.3 W and 6.7 ± 3.6 W, respectively. Moreover, greater benefits were apparent after CWT compared with CS (7.6 ± 2.7 W). However, our results also contrast with the findings of other authors, who have reported unchanged performance following CWT (Stanley et al. 2012) or CS (Ménétrier et al. 2011; Scanlan et al. 2008) when compared with PR. Discrepancies between results may depend on several factors, such as the period between the intervention and the tiring exercise, the duration of the recovery period (Stanley et al. 2012), or the application modalities of the recovery intervention. For example, when the pressure applied by the compression garments is too high, the blood flow may be decreased, while the main rational to use CS during recovery is based on the blood flow increase (Sperlich et al. 2013). It also appears that more controlled, reliable and repeatable performance measures are needed to highlight potential differences between recovery interventions, especially when small benefits are expected (Hopkins 2004). These considerations justify the major focus of our study, since as such data are lacking in the literature. Any error in measurement may mask the effect of the recovery interventions (Ménétrier et al. 2011). Therefore it is necessary to measure the variability between repeated performance tests and to ensure that it is lower than the expected changes induced by the recovery interventions (Thomas et al. 2012). In order to reach this goal, several methodological aspects were

considered. Firstly, performing tests with a constant workload until exhaustion may yield individual performances with variations of more than 25% (Billat et al. 1994; Ménétrier et al. 2011). Therefore, given the strong reproducibility (~1.5%) observed with maximal cycling exercise for a fixed duration (Chatard et al. 2004), we used this exercise to assess the efficacy of the recovery interventions. Secondly, since with the expected improvement after CWT and CS was reported to be 1.5% or more (Chatard et al. 2004), we included only participants able to reproduce the 5-min maximal cycling exercise with a variability $< 1.5\%$. After a familiarization test, the intra-participant variability was $1.2 \pm 0.2\%$ and the ICC was 0.99. This high reproducibility was obtained by including only well trained cyclists, based on a high peak power output (4.5-6 W/kg) and cycling training (4-6 sessions/week, 6-12 hours/week). Elite cyclists were not recruited because they are often justifiably reluctant to participate in controlled studies. The included participants had to be in a cycling phase (to minimize the possible training or habituation effect), but they were requested to cease competition participation during the study period (so as to not accumulate too much excessive fatigue). Additionally, all participants were previously accustomed to performing 5-min maximal exercise in training programs and competitions. With particular regard to the lack of improvements in subsequent performance most often observed with CS, this reproducible testing method with a low variability is able to detect small, but real, differences between CWT, CS and PR.

The current study also aimed to compare the effects of CWT and CS on recovery parameters usually studied in the literature, such as blood lactate concentrations and muscular soreness. Our finding of lower blood lactate concentrations following CWT and CS supports previous studies' reports of more pronounced lactate removal after CWT (Hamlin 2007; Morton 2007) and CS (Chatard et al. 2004). For an active recovery, it is well accepted that persistent low-intensity activity primarily increases blood lactate clearance by increasing muscle blood flow (Ahmaidi et al. 1996). Remaining in an upright position without moving during PR may limit the muscle pump and hence the blood lactate removal; thus, the effects of pressure caused by water and CS on the blood circulation may contribute to these changes. Studies conducted on the leg and forearm have shown that external compression may increase both venous return (Charles et al. 2011) and arterial flow rate (Bochmann et al. 2005). In addition, blood lactate removal was more pronounced after CWT compared with CS. The most probable explanations for this result are the differences in pressure gradient with CWT and CS (direction of the graduated compression: decreasing from ankle with CWT and progressive with CS; and level of compression: ~45 mmHg to the ankle with CWT (i.e. ~60 cm of water above ankle) and 15 mmHg with CS), but the current study was not designed to provide precise information on this point. The possible

Ménétrier et al. (2013). Effects of recovery using contrast water therapy or compression stockings on subsequent 5-min cycling performance. *Journal of Science and Cycling*, 2(2): 49-56

alternation of local vasoconstriction and vasodilatation during CWT may contribute to blood lactate removal. Results in the literature suggest that such an alternation exists but at subcutaneous level only (Fiscus et al. 2005; Myrer et al. 1994). To aid intramuscular blood lactate removal more effectively, temperature changes would surely be required at a deeper tissue level.

Our findings of improved perceived recovery, characterized by lower muscular soreness, following CWT (Crampton et al. 2011; Stanley et al. 2012) and CS (Chatard et al. 2004) support previous findings reporting heightened perceptions of recovery or wellbeing following both CWT and CS. The pressure applied by CWT and CS may improve perceptions of recovery or 'wellbeing' (Weiss and Duffy 1999). Moreover, cold immersion during CWT may reinforce the effects of this type of recovery on muscular soreness (Washington et al. 2000) and explain the trend toward greater benefits compared with CS.

Finally, although CWT and CS induce physiological and perceptive changes which may have a role in facilitating recovery from exercise, studies investigating the mechanisms concomitant with functional outcomes are needed to substantiate whether CWT and CS have an effect greater than simply a placebo or subjective improvement in recovery.

Practical applications

This study illustrates that when exhaustive physical exercises bouts must be repeated in a short period, the application of CWT or CS immediately after the first exercise bout improves subsequent performance. Moreover, if CWT is an available intervention, it should be used in priority compared with CS as additional performance benefits are offered. Coaches can use this information as a way of potentially improving performance of their athletes in competition format using subsequent bouts of high-intensity exercise. In cycling, these recommendations can be applied between each competition phases of mountain bike (cross-country eliminator), track (pursuits, points race, scratch, omnium...) and BMX races.

Furthermore, the results of this study reinforce interest for researchers in sports science to consider performance tests with high test-retest reproducibility, especially when small but real benefits are expected between the interventions.

In summary, this study showed a positive impact of 12-min recovery using CWT or CS on subsequent 5-min cycling performance compared with PR ($+14.2 \pm 2.3$ W and $+6.7 \pm 3.6$ W, respectively). Moreover, greater benefits were apparent after CWT compared with CS ($+7.6 \pm 2.7$ W).

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2. Lettre aux éditeurs publiée dans la revue internationale International Journal of Sport Medicine

416 Letter to the Editor

J. Pinot, F. Grappe

Letter to the Editor

Dear Editors,
 Prof Grappe and I read with interest the correspondence from Dr McGregor.
 First, we would like to reiterate the context of our study. It should be recalled that the relationship between power output and time has been studied since the second part of the XXth century (between 1954 and 1965) by Drs. Monod and Scherrer who were the pioneers in this field. Thus, the power profile is derived from these early studies with the power output measurement from power-meters. The methodology used in our manuscript takes into account the concept of *power output - time* associated with the follow-up of the power output measured in different cyclists during training and competition. We track the evolution of 13 record PO from each training and competition of cyclists to plot a *Record Power Profile* (RPP, between 1s to 4h) whereas Dr. Coggan assesses the level of the cyclists with only 4 measures from specific field tests between 5s to a theoretical point (functional threshold power). His methodology is very different from ours. We have in common the assessment of the physical potential of a cyclist, but there are many methods in existence to do this.

With regard to the terminology "*Power profile*", before our paper was published, Quod et al. [2] also used the term "*Power profile*" in a recent study (referenced in our paper). Dr. Coggan is not listed amongst the references of this paper. Thus, our title and use of the term in question is in keeping with this previous paper, but we emphasise our specific methodology for the assessment as the "*Record Power Profile*" of the cyclist. Moreover, it should be remembered that the term "*power profile*" is used routinely to describe any appraisal of power measurements over time or distance, e.g. in Wingate testing and pacing strategy research, and the term has been used in these contexts certainly before 2000. Like us, Quod et al. [2] referenced the sort of software which Dr. McGregor eludes to in his letter.

Dr. Coggan's book [1] contains no scientific references that could justify its presence in the bibliography of a scientific publication. Thus, it was not possible to refer to Dr. Coggan in the redaction of our scientific article knowing that in the first revised version of our paper, the reviewers did not accept this kind of reference. Also, to the best of our knowledge, the studies conducted by Dr. Coggan about this topic are nonexistent in the scientific literature. His works do not feature in any of the bibliographies of the articles associated with our manuscript. In France, we have no trace of Congress acts or other posts (only the article on the website TrainingPeaks.com). From there, it was difficult for us to reference his work in our paper.

An innovative character of our study is that, from our RPP we can determine 5 exercise intensity zones for the cyclist training process. In terms of the use of the word "new" in our paper, like all other researchers, we attempt to undertake novel and original studies, and this is a fundamental aspect of all articles which are peer-reviewed for all decent journals. Contribution to new knowledge is crucial in research and we maintain that our research work does contribute to new knowledge in a novel way. We are proud of this aspect.
 From these explanations, we ask for your understanding.

Sincerely,

Julien Pinot and Frederic Grappe
 Coaches of the FDJ – Bigmat Pro Cycling Team

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3. Communication orale au 35^{ème} congrès de la Société de Biomécanique au Mans en 2010, ayant fait l'œuvre d'un article dans le supplément de la revue internationale Computer Methods in Biomechanics and Biomedical Engineering

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The 'Power Profile' for determining the physical capacities of a cyclist

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Keywords: cycling; Power Profile; physical capacities; longitudinal follow-up

1. Introduction

Monod and Scherrer have determined the concept of critical power (CP) by establishing a linear relation between the time to exhaustion (T_{ex}) and (1) the total work performed (Monod and Scherrer 1965) and (2) the distance covered (Scherrer 1958). To improve this concept, Peronnet and Thibault (1987) have suggested a more elaborate model that describes the relationship between the percentage of maximal aerobic velocity and the time of exercise from 7 min to 2 h. This model allows the evaluation of three physical capacities of an athlete: T_{ex} , CP and endurance. It is possible to ameliorate this model by determining the 'Power Profile' (PP) of a cyclist. The PP can assess more physical capacities (Figure 1) from the relationship between the maximum power output (PO_{max}) sustained (during trainings and competitions) and the time between 1 s and 4 h (Larrazabal et al. 2006; Villerius et al. 2007). PO developed by a cyclist becomes a biomechanical variable of performance which is currently measured in routine directly on the bicycle during training and competition. For that, it is necessary to fix a powermeter on the bike (SRM training system or Powertap). The simplicity of use of these systems pushes the coaches and the cyclists to use PO for the training follow-up. As the level of PO is dependent on the exercise intensity, the analysis of PO during all the trainings and competitions permits the determination of the PP of the cyclist. From there, it is possible to make PP comparisons between (1) different cyclists according to the age and race category and (2) during a season for a cyclist.

The aim of this study was (1) to determine the PP during a competitive season for five cyclists of different fitness levels and (2) to analyse the inter- and intra-individual PP changes that can occur during 1 year.

2. Methods

During a cycling competitive season (February–September), five cyclists (22 ± 5 years old, 180 ± 3 cm and 66 ± 4 kg) of different levels (second category, first category, first category; member of the U23 French National team, professional in a Continental Pro Team; professional in a Pro Tour Team: top 5 in Giro and Vuelta) carried out their training and competitions with a powermeter (SRM or Powertap) on their bike. Twelve durations of the PO_{max} –time relationship were determined to emphasise the five physical capacities specific in cycling: explosiveness (1, 5 s), lactic tolerance (30 s), maximal aerobic power ~ 5 min, anaerobic threshold (20, 30, 45 and 60 min) and endurance (2, 3, 4 and 5 h) (Figure 1). The highest maintained PO value for each duration during the season was retained to determine the PP of each cyclist (PO was expressed in W/kg in order to make comparisons between the cyclists).

3. Results and discussion

The most important findings of this study are that (1) the PP allows the assessment of changes in the different physical capacities during a season for a cyclist (Figure 2) and (2) the higher the level of practice, the more the PO increases for an exercise duration (Figure 3). The level of PO is dependent on the cyclist's category. For example, at the anaerobic threshold (20–60 min), there is a mean difference of 1 W/kg between the cyclists in Pro Tour and second categories. Thus, it is possible to assess the different physical capacities for a cyclist from the PO_{max} –time relationship. The combination between the different physical capacities determines a standard PP for each athlete. This suggests that PP can represent a signature of the physical potential of the cyclist. The PP is a concept that appears very interesting for the longitudinal follow-up

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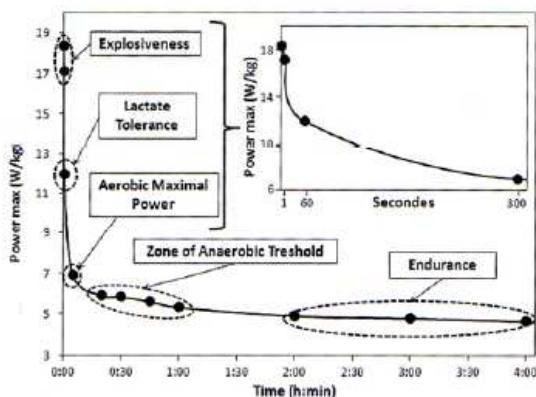


Figure 1. Determination of the different physical capacities of a cyclist from the PP.

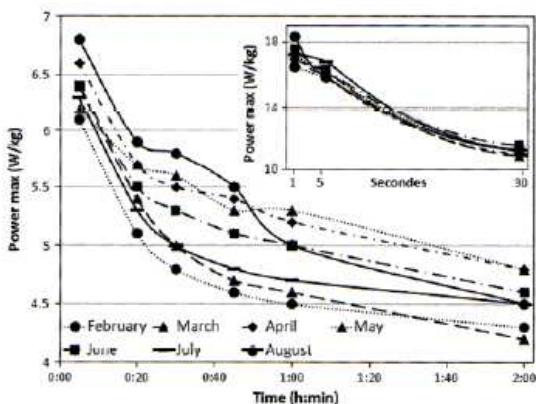


Figure 2. PO longitudinal follow-up per month for a cyclist from 1 s to 2 h durations.

of the athlete's fitness. The changes during the training follow-up allow the trainer to optimise the training process. One can follow the changes in the different physical aptitudes from the varying training loads and different kinds of races (flat, mountain, etc.). The work of the coach becomes more accurate with the possibility of making weekly/daily adjustments in the training process of the cyclist. With such training follow-up, the cyclist can

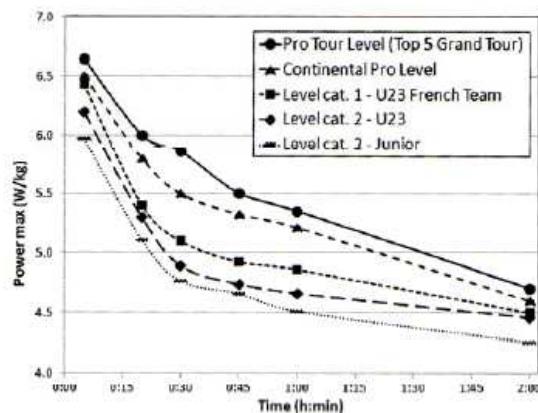


Figure 3. Changes in PP for five cyclists of different categories between 5 min and 2 h durations.

work with an overtraining prevention model and can optimise his performance capacity.

4. Conclusion

The training load longitudinal follow-up of a cyclist allows to determine his PP according to the $P_{O_{max}}$ -time relationship. One can observe the fitness changes of the athlete during the season. The PP can give a signature of the athlete's capacities.

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4. Communication orale au 36^{ème} congrès de la Société de Biomécanique à Besançon en 2011, ayant fait l'œuvre d'un article dans le supplément de la revue internationale Computer Methods in Biomechanics and Biomedical Engineering

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The Peronnet–Thibault mathematical model applied to the record power profile in cycling

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Keywords: cycling; power profile; physical capacities; endurance capability

1. Introduction

In cycling, the new concept of record power profile (RPP) allows the expression and the monitoring of the physical potential of the cyclist through the relationship between the different record power output (PO) and the time (Pinot and Grappe 2010, 2011). PO developed by a cyclist is becoming a biomechanical variable of performance, which is measured today in routine directly on the bicycle during training and competition. The RPP appears to be an innovative method for the cycling training process and the evaluation of the different physical capacities of the cyclist (Pinot and Grappe 2010).

In the 1980s, Peronnet and Thibault (1987, 1989) developed a physiological model of running performance. Their analysis provides a description of world running records. The model allows the computation of an objective measure of endurance: the index of endurance capability. They suggested that the slope of the relationship between the fractional utilisation of $\text{VO}_{2\text{max}}$ and the running time from 7 min to 2 h (expressed on a logarithmic scale) may be a convenient index of endurance capability (Peronnet and Thibault 1987, 1989). Indeed, using the fractional utilisation of $\text{VO}_{2\text{max}}$, it is possible to compare the endurance capability in runners with different $\text{VO}_{2\text{max}}$ and performance level. So, we wondered whether we could obtain the same relationship when applying this model within a broader range of time duration developed by the cyclists. To the best of our knowledge, that was not made yet.

The purpose of this study is to demonstrate that the relationship between the record PO expressed according to maximal aerobic power (%MAP) and the time (expressed on a logarithmic scale) is similar to the mathematical model of Peronnet and Thibault.

2. Methods

During a cycling competitive season (February–September), 20 cyclists carried out their training and competitions

with a powermeter (SRM Professional Training systems, Schoberer Rad Messtechnik, Jülich, Germany) on their bike. Their mean (+ SD) age, height, body mass and MAP were 24 ± 4 years, 178 ± 4 cm, 67 ± 6 kg and $6.4 \pm 0.4 \text{ W kg}^{-1}$, respectively. Ten cyclists were members of professional cycling teams. The others ($n = 10$) were elites and classed first category in France, six of whom belong to their U23 national team. All the cyclists were oriented to the high-performance level. All the data were analysed to determine the RPP of the cyclists. The different record PO corresponds to 9 maximal mean power (MMP) for times of 5, 10, 20, 30, 45, 60, 120, 180 and 240 min. The RPP of an athlete corresponds to the relationship between the 9MMP and the different durations including all the races and trainings during one season of competition from a longitudinal PO follow-up. The PO in the RPP was expressed according to the cyclist's body weight (W kg^{-1}). We chose the records PO on 5 min to express MAP, unlike to Peronnet and Thibault (1987) who have fixed the time sustained at MAP (expressed in maximal oxygen consumption) to 7 min.

3. Results and discussion

The average RPP of the 20 cyclists expressed in W kg^{-1} according to a logarithmic scale of time represents a linear regression ($R^2 = 0.99$, $p < 0.0001$; Figure 1). The aerobic record PO linearly decreases between 5 min and 4 h similarly to the model of Peronnet and Thibault (Pinot and Grappe 2010). The record PO at 5 min (between 5.5 and 7 W kg^{-1}) was close to PO at MAP evaluated in laboratory from incremental exhaustion test (Lucia et al. 2001; Faria et al. 2005). The Peronnet and Thibault model takes into account the performances between 3000 m and marathon (between 7 min and ~ 2 –3 h). In cycling, the average durations of the professional road races are between 5 and 7 h. In our cyclist population, half are elite cyclists and the races do not exceed 5 h. So, we took the record PO up to 4 h.

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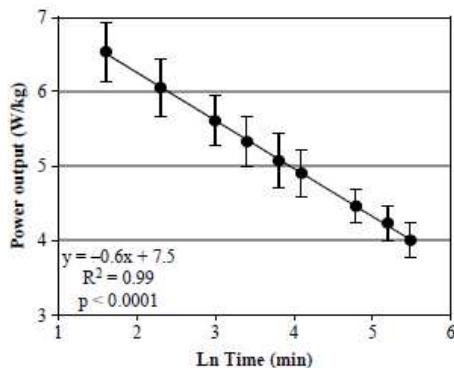


Figure 1. Average RPP expressed on a logarithmic scale of time for the 20 cyclists.

Our model allows the representation of the aerobic potential of the cyclist according to a linear regression following the equation:

$$PO = -0.6 \ln T + 7.5 \text{ (with } \ln T \text{)}$$

= natural logarithm of cycling duration in minutes).

If the decrease in PO (between 5 min and 4 h) is converted in the reduction of the fractional utilisation of MAP (%MAP), the relationship is also a linear regression ($R^2 = 0.99, p < 0.0001$; Figure 2). Thus, the relationship is similar to that observed by Peronnet and Thibault with the runners from speed measurements.

A definition generally employed for the endurance capability is the capacity to decrease the loss of power with the increase of the exercise duration (Peronnet and Thibault 1987). So, our results suggest that the slope of the linear regression between the record PO and the $\ln T$ could be an index of the endurance capability in cycling.

The mean index of endurance found in our study is -9.8 that does not correspond exactly to the index values that Peronnet and Thibault found with the runners (-4 to -8).

A future study will deal with the analysis of the index of endurance in cyclists with different skills and competition levels.

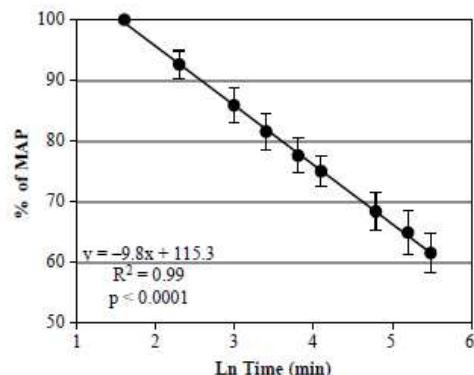


Figure 2. Reduction of PO expressed in %MAP with total cycling time for the 20 cyclists.

4. Conclusions

The results of this study show that the relationship between the fractional utilisation of MAP (according to the record PO) and the time (expressed on a logarithmic scale) is linear from a longitudinal PO follow-up among a heterogeneous population of cyclists. So, the Peronnet and Thibault model seems to be suitable with record PO measurements in cycling to determine an index of endurance from the slope of the relationship.

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O61- Indice d'endurance et profil de performance en cyclisme : étude préliminaire

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Le Profil de Puissance Record (PPR) est un concept intéressant dans le processus d'entraînement en cyclisme ; il correspond à la relation « puissance mécanique ($P_{méca}$) record – temps » d'un athlète. A partir du PPR, il est possible de dresser la relation linéaire entre la diminution du pourcentage de Puissance Maximale Aérobie et le logarithme du temps (% PMA - $\ln t$) sur des efforts de 5 min à 4 h. L'Indice d'Endurance (IE, Peronnet & Thibault, 1987) a été étudié sur 4 cyclistes professionnels à partir d'un suivi longitudinal de leur $P_{méca}$ à l'entraînement et en compétition. Les résultats préliminaires montrent qu'à partir de la mesure de la $P_{méca}$ en cyclisme il est également possible d'obtenir une relation entre le % PMA et le logarithme du temps permettant de déterminer un IE pour chaque cycliste.

Keywords: Cyclisme, Puissance mécanique, Endurance, Potentiel physique

INTRODUCTION

L'analyse de la puissance mécanique ($P_{méca}$) est aujourd'hui utilisée en routine lors du processus d'entraînement en cyclisme. Le Profil de Puissance Record (PPR) permet l'évaluation et le suivi du potentiel physique du cycliste à partir de la relation entre les $P_{méca}$ records (établies en compétition et à l'entraînement) et le temps (Pinot & Grappe, 2011). Peronnet et Thibault (1987, 1989) ont développé un modèle physiologique de la performance en course à pied qui permet de déterminer l'Indice d'Endurance (IE) d'un athlète. Cet indice correspond à la pente de la droite de régression entre la fraction d'utilisation de la VO_2max et le logarithme du temps entre 7 min et ~2 h. L'IE donne une information sur le potentiel endurant chez les athlètes. A ce jour, aucune étude n'a été conduite en cyclisme sur cette relation entre le pourcentage de Puissance Maximale Aérobie et le temps (% PMA - $\ln t$). Le but de cette étude préliminaire est 1) de déterminer les IE à partir du PPR chez 4 cyclistes professionnels ayant des profils différents et 2) comparer les IE obtenus à ceux rapportés en course à pied.

METHODES

Durant une période de 10 mois, 4 cyclistes professionnels (26 ± 5 ans, 181 ± 3 cm ; 70 ± 4 kg) ont réalisé leurs entraînements et compétitions avec un capteur de puissance SRM (Schöberer Rad Messtechnik, Jülich, Germany (Gardner et al., 2004)) fixé sur leur vélo. Chaque cycliste possédait un profil bien distinct défini à partir des performances réalisées en compétition, i.e. sprinteur, grimpeur, rouleur et mixte (sans qualité prédominante). Tous les fichiers SRM de chaque sujet ont été collectés afin de déterminer le PPR à partir des $P_{méca}$ records sur 5, 20, 30, 45, 60, 120, 180 et 240 min. Les $P_{méca}$ étaient normalisées par rapport à la masse des cyclistes (W/kg). La $P_{méca}$ record sur 5 min était considérée correspondante à la PMA.

RESULTATS

La figure 1 montre qu'il n'existe pas de différence significative (ANOVA) entre les 4 cyclistes à partir de la relation logarithmique entre les $P_{méca}$ records et le temps. Lorsque les PPR sont exprimés linéairement pour déterminer l'IE à partir de la relation % PMA - $\ln t$, le temps a une influence significative (ANOVA) ($p < 0.05$) sur la diminution du % PMA. Les tests post-hoc ne montrent aucune différence significative d'IE entre les sujets : sprinteur (IE = -8,1 ; $R^2 = 0,97$; $p < 0,001$), rouleur (IE = -9,9 ; $R^2 = 0,99$; $p < 0,001$), mixte (IE = -10,1 ; $R^2 = 0,99$; $p < 0,001$) et grimpeur (IE = -10,3 ; $R^2 = 0,99$; $p < 0,001$). En revanche, on observe d'autres tendances entre les cyclistes (voir figure 2).

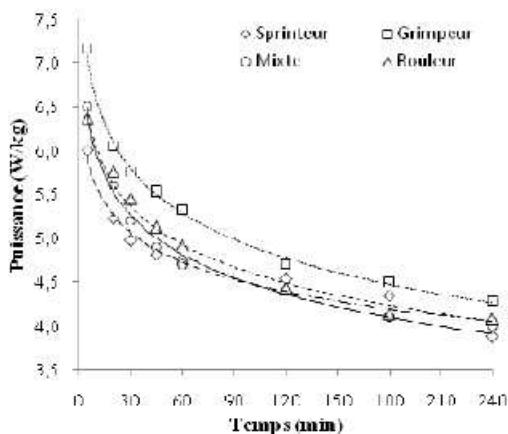


Figure 1 : Profil de Puissance Record des 4 cyclistes (Pointillés : grimpeur, tirets : rouleur, trait plein : mixte, trait discontinu : sprinteur).

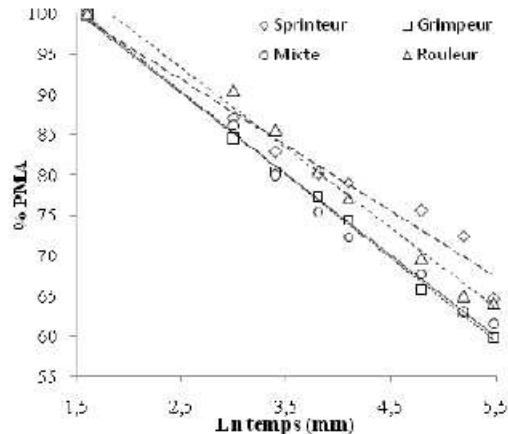


Figure 2 : Relations % PMA – $\ln t$ des 4 cyclistes (Pointillés : grimpeur, tirets : rouleur, trait plein : mixte, trait discontinu : sprinteur).

DISCUSSION

Les résultats montrent que malgré des profils de performance très différents, les 4 cyclistes possèdent des IE très proches les uns des autres. Les IE obtenus (entre -8 et -10) montrent des ordres de grandeur différents comparés à ceux obtenus par Peronnet et Thibault (entre -4 et -8) en course à pied. Le fait que la P_{meca} s'exprime avec le cube de la vitesse de déplacement peut en partie expliquer ces différences. Comme l'a souligné Vandewalle (2008), on observe que plus la courbe du PPR est incurvée, plus l'IE est faible à l'instar du sprinteur. Selon Péronnet et Thibault, plus l'IE est faible (se rapprochant de 0) et plus le potentiel d'endurance est élevé. L'IE traduisant la faculté à soutenir un haut pourcentage de PMA pour un temps donné ne semble pas lié au profil du coureur en cyclisme puisque pour quatre profils différents les IE sont relativement proches. Péronnet et Thibault ont souligné que le poids de l'IE était moindre comparé à celui de la $VO_2\text{max}$ dans la réalisation d'une performance en endurance. Une erreur de 1% de la PMA peut provoquer jusqu'à 16% d'erreur dans la pente de la relation % PMA – $\ln t$ (Vandewalle 2008). Ainsi, la détermination d'un IE fiable répond nécessairement à un PPR précis obtenu à partir de mesures valides de la P_{meca} sur une durée assez longue (plusieurs mois) afin de se rapprocher le plus possible des records de P_{meca} entre des durées comprises entre 5 min et 4h.

CONCLUSION

Cette étude préliminaire montre que les pentes obtenues à partir de la relation % PMA – $\ln t$ permettent de définir des IE propres à chaque cycliste. Les résultats ne montrent pas de différence significative d'IE en fonction du profil de coureur. De futures études conduites sur un échantillon plus important de cyclistes de niveaux et de profils différents permettront de mieux analyser l'IE et son influence sur la performance en cyclisme.

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6. Communication orale au 15^{ème} congrès de l'ACAPS à Grenoble en 2013.

06-3 |

Analyse de la puissance mécanique au niveau du bassin en position danseuse en cyclisme

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Mots clés (5 au maximum) :Puissance Mécanique ; Energie ; Technique de pédalage ;

INTRODUCTION

En montée, la plus grande partie de la puissance mécanique ($P_{méca}$) développée par le cycliste sert à lutter contre la gravité. Alors que sur un parcours plat le cycliste reste majoritairement en position assise, lorsqu'il roule en montée il alterne souvent entre les positions assise et danseuse selon différents paramètres : le pourcentage et la longueur de la pente, le développement utilisé, l'expérience et ses dimensions corporelles. En passant de la position assise à celle en danseuse, le redressement du buste et l'avancée du bassin permettent des oscillations du corps et du vélo qui entraînent une modification de l'orientation des forces appliquées sur la pédale (Caldwell et al., 1998). L'alternance entre les deux positions permet au cycliste de mettre en action différemment la chaîne musculaire des membres inférieurs et de profiter d'une force externe positive qui s'ajoute à la phase de poussée de la pédale : la gravité avec le poids du corps (Duc et al, 2008). Au niveau physiologique, Millet et al, (2002) ont montré qu'il n'existant aucune différence en termes d'efficacité et de rendement entre les positions assise et danseuse. L'étude des oscillations du bassin en danseuse autorise l'analyse de l'énergie mécanique à partir des variations de vitesses créées lors de chaque coup de pédale. A notre connaissance, aucune étude n'a encore mesuré l'énergie mécanique au niveau du bassin dans cette condition. L'objectif de cette étude a été de comparer la $P_{méca}$ totale développée au niveau du bassin (P_{bassin}) avec la $P_{méca}$ utile à l'avancement mesurée au niveau du moyeu de la roue arrière (P_{roue}) avec un groupe de cyclistes compétiteurs élites. P_{bassin} et P_{roue} ont également été comparées avec la $P_{méca}$ estimée à partir d'un modèle théorique($P_{théo}$).

METHODES

Treize cyclistes élites (23 ± 4 ans, 177 ± 5 cm et 65 ± 8 kg) ont participé à cette étude. La mesure de P_{bassin} a été réalisée à l'aide d'un bras cinématique (Belli et al., 1992) consistant en 4 segments en aluminium reliés entre eux par 3 articulations mono-axiales. L'extrémité du bras était reliée à une ceinture attachée au bassin du sujet. L'exercice se déroulait avec le vélo personnel de chaque cycliste équipé d'une roue arrière possédant un capteur de puissance Powertap (CycleOps, Madison, USA) sur un tapis roulant motorisé (S1830, HEF Techmachine, Andrézieux-Bouthéon, France). La $P_{théo}$ a été calculée d'après la formule utilisée par Henchoz et al. (2010). Après une séance d'habituation sur le tapis, chaque cycliste effectuait 4 paliers de 2 min sur 4 pentes différentes (5, 7, 9 et 11%) à des vitesses normalisées en fonction d'une $P_{méca}$ constante équivalente à 4.6 W/kg. Trois enregistrements de 10 secondes en positions assise et danseuse étaient effectués sur chaque palier.

RESULTATS

Tableau 1. $P_{\text{méca}}$ (W/kg) calculées selon les 3 méthodes différentes

(W/kg)	5%	7%	9%	11%
	Moy	Moy	Moy	Moy
$P_{\text{théo}}$	4,5 ± 0,2	4,6 ± 0,2	4,6 ± 0,1	4,7 ± 0,1
P_{roue}	4,6 ± 0,3	4,6 ± 0,2	4,6 ± 0,2	4,7 ± 0,2
P_{bassin}	29,7 ± 19,6	22,6 ± 12,6	19,7 ± 9,9	16,4 ± 7,7
$P_{\text{bassin}}^{\text{potentielle}}$	1,3 ± 1,1	1,4 ± 1,7	1,2 ± 1,3	1,2 ± 1,3
$P_{\text{bassin}}^{\text{cinétique}}$	29,5 ± 19,5	21,9 ± 13,2	19,8 ± 9,8	16,4 ± 8,1

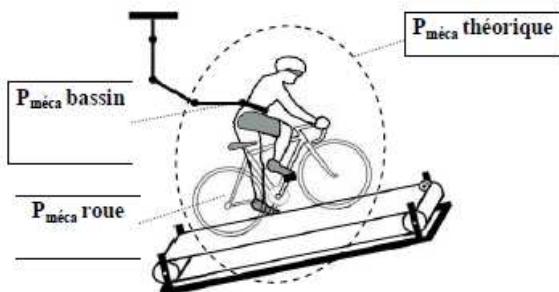


Figure 1. Représentation du cycliste équipé du bras cinématique sur le tapis roulant

L'analyse ANOVA indique que P_{bassin} totale est significativement plus élevée (4 à 7 fois plus élevée selon la pente) que P_{roue} et $P_{\text{théo}}$. P_{bassin} cinétique représente entre 90 et 95 % de P_{bassin} totale et est largement prédominante par rapport à la part de P_{bassin} potentielle. D'importantes différences interindividuelles sont observées entre les cyclistes au niveau de P_{bassin} . $P_{\text{théo}}$ et P_{roue} sont similaires, ce qui confirme la validité de la mesure de P_{roue} .

DISCUSSION & CONCLUSION

Les résultats montrent que lorsque le cycliste est en danseuse, les oscillations du bassin produisent une importante quantité d'énergie mécanique largement supérieure à celle utile pour la locomotion. En effet, P_{roue} ne représente que 15 à 30 % de P_{bassin} selon la pente. Cela suggère qu'une importante quantité d'énergie produite au niveau du bassin est dissipée lors du mouvement de pédalage en danseuse. En passant de la position assise à celle en danseuse, le bassin s'élève et s'avance pour ne plus être en appui sur la selle. Cette nouvelle posture modifie l'action des chaînes musculaires des membres inférieurs et supérieurs et donc la transmission des forces sur les pédales. En position assise, le mouvement de pédalage est produit par l'action essentiellement concentrique de la chaîne musculaire des membres inférieurs. Cependant Hawkins & Hull (1990) ont montré qu'il pouvait exister un petit stockage d'énergie élastique. Ainsi, à partir d'une technique efficace, certains cyclistes pourraient utiliser un petit supplément d'énergie mécanique gratuite dans la production de puissance en danseuse. Les importantes différences interindividuelles de P_{bassin} entre les sujets montrent qu'il existe des techniques en danseuse très différentes d'un cycliste à l'autre. Certains à l'aise, sont fréquemment en danseuse en montée alors que d'autres moins à l'aise, rouent plus souvent assis. De futures études devront montrer s'il existe un modèle biomécanique idéal du pédalage en danseuse dans différents pourcentages en montée.

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BOOK OF ABSTRACTS

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Comparison of power output demands for a top-10 ranking between Tour de France and Vuelta a España

J Pinot ^{1,2}✉ and F Grappe ^{1,2}

Abstract

Background: Grand Tours (GT) are extreme endurance cycling events with about 3500 km covered in twenty-one stages during three weeks. Using the heart rate measurement, Lucia et al. (Lucia et al., 2003; Medicine & Science in Sports & Exercise, 35(5), 872-878) showed that the total exercise load (volume x intensity) do not differ between the Tour de France (TdF) and Vuelta a Espana (VaE). Since powermeters are daily used by the professional cyclists, there are some studies which investigated power output (PO) during Grand Tour but none has made PO measurement on a top-10 overall ranking cyclist to compare PO in different intensity zones in TdF and VaE.

Purpose: The purpose of this study was to compare the physical performance level between TdF and VaE of a top-10 overall ranking cyclist from PO measurements.

Methods: The PO data of a cyclist (23 yrs, 180 cm and 65 kg) who finished in the top-10 overall ranking in TdF 2012 (10th) and VaE 2013 (7th) were analysed to evaluate the physical performance level on each race from 1/ the determination of the Record Power Profile (RPP) of TdF and VaE according to the methodology of Pinot and Grappe (Pinot & Grappe, 2011; International Journal of Sports medicine, 32, 839-844) and 2/ the comparison of the maximal efforts in the five exercise intensity zones defined from the RPP.

Results: Figure 1 shows the RPP of the cyclist in TdF and VaE. The performance level in the low part of the severe intensity (zone 3) is similar in the two GT (Table 1). In the heavy intensity (zone 2) there is a slight increase (+1.6%) of the performance level in VaE. The level of performance in moderate intensity (zone 1) and in force-velocity (zone 5) are higher in the Tdf (5.1% and 2.6%, respectively) while it's the opposite in the high part of severe intensity (zone 4) (+6.9% in VaE).

Discussion: This study shows that the maximal efforts made between 5 and 60 min both in the TdF and VaE are very close in a top-10 overall ranking. This result means that the cyclist performed in the heavy and in the low part of the severe intensity zones at the same physical level of performance in the two GT although the characteristics of the roads were different (11 summit finishes & 36 km of individual time trials (ITT) in VaE 2013 vs. 4 summit finishes in Tdf 2012, longer stages (+8%) and 100 km of ITT). The results are in accordance with the specificity of the efforts performed between the maximal aerobic power (MAP) and the anaerobic threshold to get a ranking in the top 10 in a GT. Indeed, the general classification in a GT usually plays in mountain ascents and during ITT. The shorter and steeper finish ascents in VaE could explain why the record PO between 30 sec and 5 min were higher than in TdF. The higher level of performance in TdF in moderate intensity is due to a long breakaway of the cyclist performed to go win a stage.

Conclusion: To achieve an overall ranking top 10 in a GT, the level of performance in the heavy and in the low part of the severe intensity zones is essential. To get there, the levels of both MAP and anaerobic threshold must be the highest possible.

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Comparison of power output demands for a top-10 ranking between Tour de France and Vuelta a Espana



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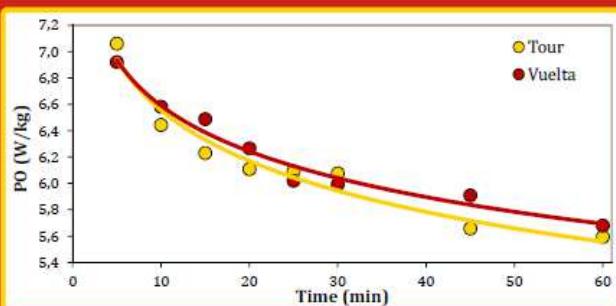
Introduction

Grand Tours (GT) are extreme endurance cycling events with about 3500 km covered in twenty-one stages during three weeks. Using the heart rate measurement, Lucia *et al.* [1] showed that the total exercise load (volume x intensity) do not differ between the Tour de France (TdF) and Vuelta a Espana (VaE). Since powermeters are daily used by the professional cyclists, there are some studies which

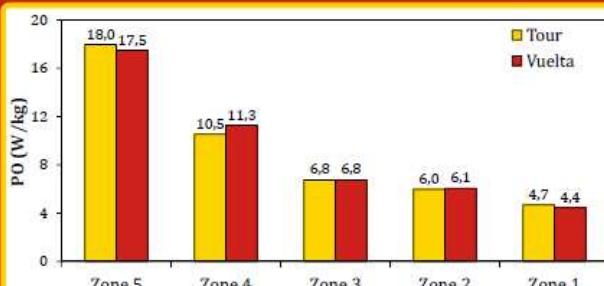
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	1''	5''	30''	1'	5'	10'	15'	20'	25'	30'	45'	60'	120'	180'	240'
TOUR	18,2	17,7	11,2	9,9	7,1	6,4	6,2	6,1	6,1	6,1	5,7	5,6	4,8	4,7	4,5
VUELTA	18,2	16,8	13,0	9,5	6,9	6,6	6,5	6,3	6,0	6,0	5,9	5,7	4,7	4,5	4,1



Results

The performance level in the low part of the severe intensity (zone 3) is similar in the two GT. In the heavy intensity (zone 2) there is a slight increase (+1.6%) of the performance level in VaE. The level of performance in moderate intensity (zone 1) and in force-velocity (zone 5) are higher in the Tdf (5.1% and 2.6%, respectively) while it's the opposite in the high part of severe intensity (zone 4) (+6.9% in VaE).

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