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# Validity and Reliability of the Axiom Powertrain Cycle Ergometer When Compared with an SRM Powermeter

**Abstract**

The purpose of this study was to determine the validity and the reliability of a stationary electromagnetically-braked cycle ergometer (Axiom PowerTrain) against the SRM power measuring crankset. Nineteen male competitive cyclists completed four tests on their bicycle equipped with a 20-strain gauges SRM crankset: a maximal aerobic power (MAP) test and three 10-min time trials (TTs) with three different simulated slopes (0, 3, and 6%). The Axiom ergometer overestimated ($p < 0.05$) the SRM power output during the last stage of the MAP test and during TTs, by 5% and 12%, respectively. Power output (PO) of the Axiom ergometer drifted significantly ($p < 0.05$) with the time during TT. These findings indicate that the Axiom ergometer does not provide a valid measure of PO compared with SRM. However, the small coefficient of variation (2.2%) during the MAP test indicates that the Axiom provides a reliable PO and that it can be used e.g. for relative PO comparisons with competitive cyclists during a race season.

**Key words**
Power output · SRM system · Axiom PowerTrain · accuracy

## Introduction

It is common to use laboratory tests in order to evaluate the performance of competitive cyclists [19]. To predict cycling performance or to evaluate training effects, different laboratory tests are performed that determine the maximal power output during sprint [20], the maximal aerobic power (MAP, W), or the power output (PO, W) during simulated time trial (TT) [9,18]. Indeed, PO of a competitive cyclist is a key determinant of endurance performance [6].

Different stationary and mobile cycle ergometers can be used for tests that measure the cyclist's PO. Stationary bicycle ergometers can be electromagnetically-braked (e.g. Velodyne, Lode Excalibur, Avantronic Cyclus, Ergomeca), friction-braked (e.g. Monark), or air-braked (e.g. Kingcycle, Repco) [17]. The "gold standard" stationary ergometer used in the laboratory was the Monark cycle ergometer [17]. However, experienced cyclists have difficulties in adapting their normal riding position during laboratory tests with a Monark ergometer. So, stationary electromagnetically-braked and air-braked ergometers have appeared that attach to a cyclist's own bicycle. In the last few years, mobile ergometers (e.g. SRM, Polar S710, PowerTap, Ergomo) have come into use to measure performance in laboratory or field conditions and allow cyclists to use their own bicycle. All these available stationary and mobile ergometers differ in quality of PO measurement [17].

However, with the purpose to perform scientific research or to evaluate training effects, it is essential to use an ergometer that provides a valid and reliable measure of PO and that is comparable with other ergometers within an acceptable range of technical error [2]. From this point of view, Paton and Hopkins [17] stated in their critical review that the Monark was not the "gold standard" as it was always thought and that the SRM system appeared to be the best ergometer to measure the PO developed by



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a cyclist in field or in laboratory. The SRM system (SRM, Jülich, Welldorf, Germany) is a crankset with strain gauges which can be fitted to a racing bicycle. Jones and Passfield [11] have shown the validity and the reliability of the SRM when compared with the Monark ergometer.

Despite the recent evolutions of mobile ergometers, still numerous makes of stationary electromagnetically-braked ergometers are being produced. Especially for recreational and competitive cyclists different electromagnetically-braked ergometers are available. One of them is the Axiom PowerTrain (Axiom) cycle ergometer (Elite s.r.l., Fontaniva, Italy). The Axiom is a stationary electromagnetically-braked computerized ergometer. By fixing the rear wheel in the stand of the ergometer by the rear wheel quick release skewer, cyclists can use their own bicycle. The resistance in this stationary ergometer is obtained by an electromagnetic brake applied on a roller, that is in contact with the rear wheel. Due to a control algorithm in the Axiom software, an electromagnetic braking force in the resistance unit is applied to emulate wind resistance, rolling resistance, and gravitational resistance for real road cycling conditions. The Axiom ergometer is used by many professional cycling teams (e.g. Quick Step, Team Bianchi, Fassa Bortolo, Gerolsteiner, Kelme, Saeco, Lampre, Fdjeux.com, Jean Delatour), sports medical institutes (i.e. "Centro Sportivo Service Mapei"), sports doctors, cycling trainers, and many recreational and competitive cyclists from regional to professional level.

Although not designed for scientific purposes, it would be interesting to know how accurate and reliable such a popular ergometer is, and if it could be used for scientific research. To the best of our knowledge, the validity and reliability of the Axiom ergometer by comparing with other ergometers has never been investigated. During prior preliminary tests with an SRM-equipped bicycle on the Axiom ergometer, we already observed some remarkable findings. Differences between Axiom and SRM PO seemed to vary according to different simulated slopes. Also we found out that a slope close to 6% corresponds to the maximal braking torque (close to 1 Nm) that the Axiom ergometer can provide. So we thought it would be interesting to know whether the validity of the Axiom was maintained over the whole range of braking forces that are producible by the Axiom electromagnetic resistance unit. We decided to test three different simulated slopes of 0, 3, and 6% during three 10-min time trials (TTs), because a TT protocol is often used in scientific researches on cycling and during performance tests with cyclists. The duration of 10 min made it possible to perform these three TTs on the same day, while minimising fatigue effects. Besides, 10 min seemed long enough to investigate if there was a drift in PO.

We also wondered if the Axiom ergometer was able to produce a valid and reliable standardised MAP test.

Thus the aim of this study was to assess the validity and reliability of the Axiom power output ($PO_{axiom}$) compared with a high accuracy [12] 20-strain gauges SRM crankset during a MAP test and three 10-min TTs exercises with three different simulated slopes (0, 3, and 6%), in order to state if the Axiom could be used for scientific research on cycling and performance tests with competitive cyclists.

## Materials and Methods

### Subjects

Nineteen male competitive cyclists (age: 30.3 ± 8.4 years, height: 178 ± 7.0 cm, body mass: 72.5 ± 6.2 kg) ranging from regional to national level (cycling experience: 10.3 ± 5.8 years) volunteered as subjects for this study. Prior to testing and after having been fully explained about the nature and purpose of the study, each subject gave written informed consent. The study was approved by the institute's ethics committee. Subjects were requested to refrain from strenuous physical activities for the 48 h prior to each test. Before participating subjects underwent a habituation session in order to familiarise themselves with the testing procedure and the simulated grades.

### Instrumentation

Subjects performed all tests with their own racing bicycles equipped with clipless pedals. The bicycle tyre pressure was inflated to 700 kPa. The bicycle was fitted with a 20-strain gauges SRM crankset and was attached to a computerized Axiom ergometer. The rear wheel of the bicycle was fixed by the rear wheel quick release skewer in the stand of the ergometer. This stand prevents lateral motion of the rear wheel. The same rear wheel was used for all tests. A roller, that was connected with a flywheel in an electromagnetic resistance unit, was brought in contact with the tyre. The pressure of the roller on the rear wheel was adjusted by rotating a screw. This pressure was standardised by the following procedure: the roller was brought in contact with the tyre and then the screw was turned another 540 degrees. Unfortunately, the Axiom has not his own specified calibration procedure. The Axiom ergometer indicated and recorded power output ($PO_{axiom}$, W). The $PO_{axiom}$ was calculated by the Axiom software with the following equation (from the manufacturer, Elite s.r.l.):

$$PO_{axiom} = a \cdot V^5 + b \cdot V^4 + c \cdot V^3 + d \cdot V^2 + (e + f \cdot weight \cdot slope) \cdot V$$

With Velocity (V) measured in $km \cdot h^{-1}$,
a = 0.0000066666,
b = – 0.00095833,
c = 0.0495,
d = – 0.84416,
e = 5.983,
f = 0.02722.

These coefficients were calculated by Elite s.r.l. from a polynomial regression with SRM measurements that were obtained in the field by cycling at different velocities, slopes and with different body masses. As can be seen in the equation, the pedalling cadence does not have a direct effect on the $PO_{axiom}$ values. On the Axiom device the $PO_{axiom}$ is influenced by the roller velocity. The same roller velocity can be obtained with different combinations of pedalling cadence and gear ratio. Throughout each test, $PO_{axiom}$ was recorded every 5 s. Before each test, the SRM crankset was calibrated according to the manufacturer's recommendations that have been previously described in detail by Jones and Passfield [11]. The SRM stored the power output ($PO_{SRM}$), the pedalling cadence (rpm), and the heart rate (HR) every 5 s. Throughout each trial laboratory conditions were maintained: ambient temperature 20 – 25 °C, relative humidity 41 – 54%.

**MAP test**

The protocol of the MAP test started at a workload of 130 W for 2 min and was increased by 30 W every 2 min until exhaustion. The pedalling cadence was kept constant throughout the test at 90 rpm. To maintain this cadence, the subject referred to the SRM powercontrol unit clamped on the handlebars of his road-racing bicycle. Exhaustion was defined as the incapacity of the subject to maintain the pedalling cadence of 90 rpm despite strong verbal encouragements. All subjects were verbally encouraged by the same person.

To perform this MAP test protocol with the Axiom, a race was created in the Axiom computer programe, that resulted in these workload increments and stage durations. The body mass of the rider in the Axiom PowerTrain programe was thereby standardised at 66 kg and the gear ratio that was used was standardised at 39/17. These standardisations were necessary to keep the calculated $PO_{axiom}$ (and thus brake regulation) the same for every stage for each subject. Workloads were realised by simulating uphill slopes. The MAP test started with a simulated grade of 0.7% and next the simulated grade increased every 2 minutes with 0.7% increments. Workload increments for subsequent stages were obtained by changing gear ratio while maintaining the simulated grade at 5.6% and the pedalling cadence at 90 rpm. The mechanical variables of the MAP test are shown in Table **1**.

During 1 min every stage, 5 sec-sampling values of $PO_{axiom}$ and $PO_{SRM}$ were averaged. PO data was averaged between the 30th and the 90th seconds of each stage, to take into account PO variations at the beginning of each stage. These were the result of the slope changes, because it took the resistance unit a few seconds to stabilise the braking force and subjects also required some seconds of time to readjust their pedalling cadence at 90 rpm. The MAP was determined by the PO at the last stage of the test fully completed.

**TT tests**

Each cyclist completed three laboratory 10-min self-paced TTs which were spaced by 15 min rest. The resistance of the Axiom electromagnetic brake for each TT was randomised and corresponded to a slope in the Axiom computer program of 0.8% (TT0%), 3% (TT3%), and 6% (TT6%). We were aware of the risks of fatigue during this TT protocol, due to lactate accumulation and glycogen depletion. However, by randomisation we tried to avoid fatigue effects and we even encouraged the subjects to drink carbohydrate energy drinks during the 15-min recovery periods. Before the TT session, riders were instructed to perform a warm up as they were used to before a real TT race. During each TT, subjects were informed only of elapsed time and received no information about their PO, velocity, heart rate, and pedalling cadence. For the two 15-min recovery periods, subjects were instructed to recover as best as possible within these 15 min. The subjects recovered in the way they preferred, either by continuing to cycle or by descending from their bicycle to stretch their leg muscles. The only restrictions were that they had to cycle for 2–3 minutes after and before each TT. For comparison purposes during the TTs, the mean PO values for every minute were obtained, by averaging the 5 sec-sampling values of $PO_{axiom}$ and $PO_{SRM}$ of the last 30 s of each minute. Also, the braking torque applied on the Axiom roller was calculated every minute for each TT from the Axiom roller velocity ($rad \cdot s^{-1}$) and the $PO_{SRM}$ value.

To compare the simulated Axiom slopes and the slopes corresponding to the field during this study we used the equation of cyclist motion determined by Martin et al. [13] (Table **2**). The simplified Martin equation was:

$$PO = [(Va^2 V_G 1/2\rho(C_D A + F_w) + VGC_{rr} m_T g + V_G(91 + 8.7V_G)10^{-3} + V_G m_T g G_R]/E_C$$

With, the air velocity $V_a$ (m/s), the velocity of the bicycle and rider $V_G$ (m/s), the air density $\rho$ (kg/m$^3$), the coefficient of drag $C_D$, the frontal area A (m$^2$), $F_w$ the factor (0.0044) associated with the wheel rotation that represents the incremental drag area of the spokes (m$^2$), the coefficient of rolling resistance $C_{rr}$, the total mass of bicycle and rider $m_T$ (kg), the acceleration of gravity g (9.81 m/s$^2$), the road gradient $G_R$ (rise/run), and the chain efficiency factor $E_C$ (0.976). For this calculation, a mean $C_DA$ of 0.3 m$^2$ and a $C_{rr}$ of 0.005 were used, based on studies of Candau et al. [5] and Grappe et al. [8].

The body mass of each cyclist was determined just before the TTs and entered in the Axiom computer programme before the start of the first TT.

**Statistics**

Pearson's product moment correlation coefficient (r) was used to determine the degree of association between: 1) $PO_{axiom}$ and $PO_{SRM}$ during the MAP test, 2) the time and the bias (difference between $PO_{axiom}$ and $PO_{SRM}$, defined as $PO_{axiom} - PO_{SRM}$) during $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$, 3) the pedalling cadence and the bias during $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$, and 4) the time and the mean braking torque applied on the Axiom roller in the resistance unit during all TTs. The 95% levels of agreement of the PO differences between SRM and Axiom ergometers for the MAP test and TTs were defined using the method of Bland and Altman [4]. The PO differences were drawn in relation to the mean values and 95% of the differences were expected to lie between the two "limits of agreement" that were mean difference ± 2 standard deviation (SD) of the differences, expressed as bias ± random error as recommended by Atkinson and Nevill [1]. 95% confidence interval (95%CI) for the bias were also calculated. MAP test data were checked on heteroscedasticity by calculating heteroscedasticity correlation as described by Atkinson and Nevill [1]. After testing our data for normality and homogeneity of variance, the analysis of differences between the mean $PO_{axiom}$ and $PO_{SRM}$ of each stage of the MAP test and of $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$ were assessed with paired (non parametric) Wilcoxon tests. Time effects during the TTs for 1) $PO_{axiom}$ and $PO_{SRM}$ and 2) pedalling cadence were evaluated with a non parametric one-way (time) repeated measures test (Friedman). A pairwise multiple comparison procedure using Tukey test was conducted to determine the significant differences between the time intervals.

The coefficient of variation (CV) of PO of each stage during the MAP test was determined for $PO_{axiom}$ and $PO_{SRM}$. CV was calculated as the ratio of the standard deviation by the mean, multiplied by 100. Mean CV for $PO_{axiom}$ and $PO_{SRM}$ during the MAP test was calculated as the average of all corresponding CV values of all stages. Significant difference was set at $p < 0.05$. Data are presented as mean values ± SD.

## Results

Data were not normally distributed, and the correlation between the absolute differences between SRM and Axiom and the mean PO was ($r = 0.4$, $p = 0.99$). Although this correlation was not significant and thus heteroscedasticity was not present, the data were logarithmically transformed according to Nevill [15] and Nevill and Atkinson [16], and the correlation was reduced ($r = 0.02$).

### MAP tests

There was a strong correlation ($r = 0.99$, $p < 0.001$) between the PO measured with the two devices (Fig. **1**). During the MAP test, the $PO_{axiom}$ from stage 4 to 9 and at MAP were significantly ($p < 0.05$) higher compared with the $PO_{SRM}$ (Table **1**) whereas there were no significant differences between the other stages. The Axiom MAP value (PO for the final stage of each subject) was overestimated by 4.9 ± 2.9% compared with the corresponding $PO_{SRM}$ (388 ± 25 *vs* 370 ± 20 W, respectively). The ratio limits of agreement of the PO differences between the two systems during the MAP test were 1.031 (95%CI = 1.020 – 1.041) × ÷ 1.114. The mean CV in PO for all the stages of the MAP test was 4.1% and 2.2%, respectively for the SRM and Axiom.

### TT tests

The correlation coefficients between the $PO_{SRM}$ and the $PO_{axiom}$ during $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$ were: $r = 0.77$, $r = 0.79$, and $r = 0.89$ ($p < 0.01$), respectively. The mean $PO_{axiom}$ measured during $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$ was significantly ($p < 0.05$) higher (338 ± 26 vs. 295 ± 25 W, 321 ± 21 *vs* 293 ± 24 W, 326 ± 28 *vs* 301 ± 25 W, respectively) compared with the $PO_{SRM}$. The ratio limits of agreement of the PO differences between the two systems during TT tests were 1.115 (95%CI = 1.116 – 1.173) × ÷ 1.056, 1.095 (95%CI = 1.070 – 1.121) × ÷ 1.107 and, 1.079 (95%CI = 1.061 – 1.097) × ÷ 1.075 respectively for $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$. The bias between the Axiom and SRM was highly correlated ($p < 0.001$) according to the time ($r = 0.88$, 0.96, and 0.98, respectively for $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$) (Fig. **2**). The bias between the Axiom and SRM was also highly correlated ($p < 0.01$) according to the pedalling cadence ($r = 0.96$, 0.98, and 0.96, respectively for $TT_{0\%}$, $TT_{3\%}$ and $TT_{6\%}$) (Fig. **3**). The decrease of the braking torque applied on the Axiom roller was highly correlated ($r = 0.94$) according to the time (Fig. **4**).

The Friedman and Tukey *post hoc* analysis indicated that $PO_{axiom}$ increased according to the duration of exercise ($p < 0.001$), contrary to the $PO_{SRM}$ (Fig. **5**). The $PO_{axiom}$ increased ($p < 0.01$) from the start to the end for each of the three TTs. The $PO_{axiom}$ at the end of each TT was significantly ($p < 0.05$) higher (+ 4.5%, 6.1%, and 6.4% for the $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$, respectively) compared with the $PO_{axiom}$ of the first minute. During the $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$ (between the 1st and the 10th min), the mean pedalling cadence increased ($p < 0.05$) from 93 ± 6 to 97 ± 7 rpm, from 93 ± 6 to 98 ± 7 rpm, and from 88 ± 5 to 96 ± 8 rpm, respectively. The Axiom slopes simulated during the $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$ were overestimated compared with the theoretical slopes corresponding to the field (0.8 *vs* 0.1%, 3 *vs* 2.4%, and 6 *vs* 4.6%, respectively) calculated with the theoretical equation of Martin et al. [13] with the TT data (Table **2**).

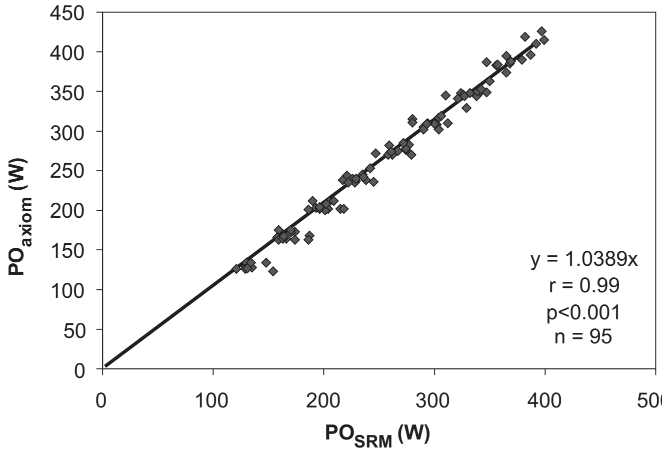


Fig. **1** Correlation analysis between $PO_{axiom}$ and $PO_{SRM}$ during the MAP test.

Table **1** $PO_{axiom}$ and $PO_{SRM}$, gear ratio, and Axiom slope during the MAP test

| *Stages* | *Axiom grade (%)* | *Gear ratio* | *Mean $PO_{SRM}$ (W)* | *Mean $PO_{axiom}$ (W)* |
|---|---|---|---|---|
| *1* | 0.7 | 39/17 | 134 ± 9 | 130 ± 5 |
| *2* | 1.4 | 39/17 | 168 ± 10 | 168 ± 5 |
| *3* | 2.1 | 39/17 | 201 ± 10 | 205 ± 4 |
| *4* | 2.8 | 39/17 | 229 ± 9 [a] | 240 ± 5 |
| *5* | 3.5 | 39/17 | 265 ± 10 [a] | 276 ± 5 |
| *6* | 4.2 | 39/17 | 295 ± 10 [a] | 310 ± 5 |
| *7* | 4.9 | 39/17 | 330 ± 11 [a] | 345 ± 6 |
| *8* | 5.6 | 39/17 | 364 ± 12 [a] | 385 ± 9 |
| *9* | 5.6 | 39/16 | 392 ± 8 [a] | 417 ± 7 |

$PO_{axiom}$: Axiom power output; $PO_{SRM}$: SRM power output; [a] significantly different compared with $PO_{axiom}$ ($p < 0.05$)

## Discussion

The major finding of this study is that $PO_{axiom}$ during the last stage of MAP test and during the three TT tests was significantly higher (mean + 5% and + 12%, respectively) compared with $PO_{SRM}$ and that the Axiom ergometer does not provide a valid PO measurement.

### Validity of $PO_{axiom}$

#### *MAP tests*

The mean $PO_{axiom}$ at MAP was significantly ($p < 0.05$) higher (+ 4.9 ± 2.9%) compared with the $PO_{SRM}$ (388 ± 25 *vs* 370 ± 20 W, respectively). In spite of a correlation coefficient between the two PO measurements during the MAP test of $r = 0.99$ ($p < 0.001$) (Fig. **1**), the bias × ÷ random error between Axiom and SRM PO for all stages was 1.031 (95%CI = 1.020 – 1.041) × ÷

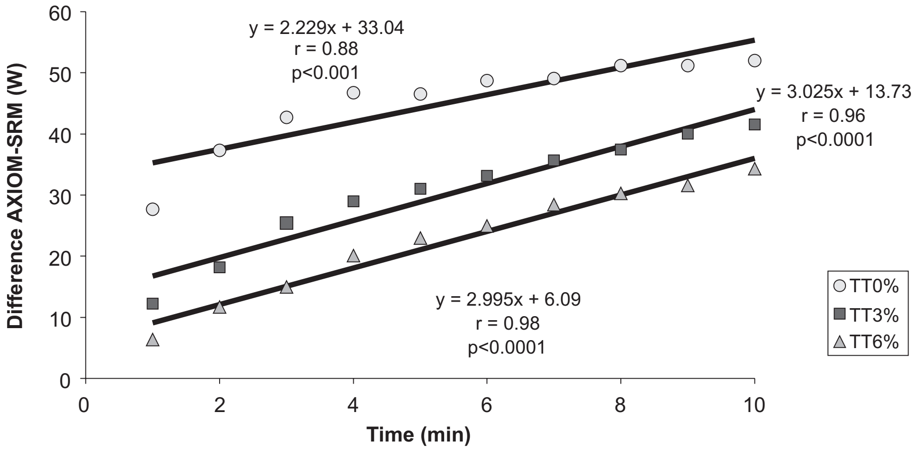


Fig. 2 Correlation analysis between $PO_{axiom}$ and $PO_{SRM}$ bias during the 3 TTs and the duration of exercise. * Significantly different according to the time $p < 0.05$.

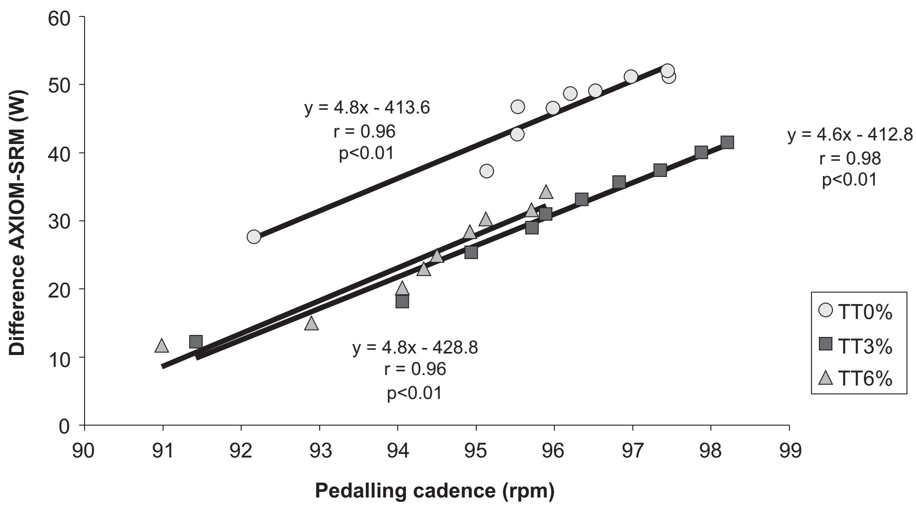


Fig. 3 Evolution of bias between $PO_{axiom}$ and $PO_{SRM}$ the 3 TTs according to the pedalling cadence.

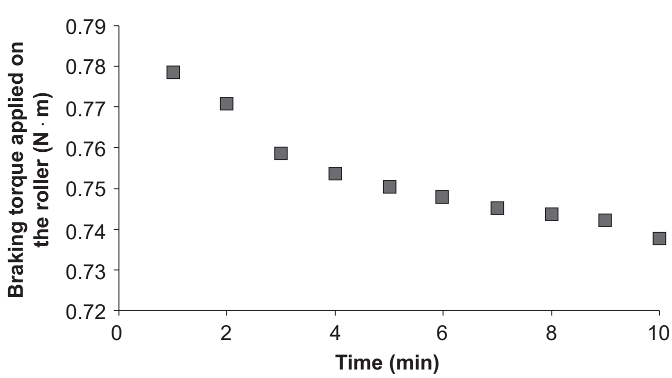


Fig. 4 Evolution of the mean resistive braking torque on the Axiom roller according to the time for the 3 TTs.

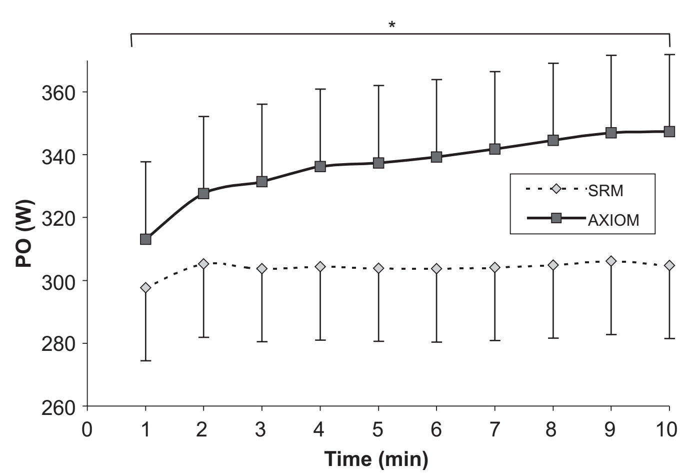


Fig. 5 Mean TT $PO_{axiom}$ and TT $PO_{SRM}$ evolution according to the duration of exercise. * Significantly different according to the time $p < 0.05$.

1.114 (representing absolute PO differences of 9 ± 25 W), which signifies that the $PO_{axiom}$ was overestimated compared with the $PO_{SRM}$. These results indicate that the Axiom ergometer does not provide a valid PO measurement during the MAP tests compared with the SRM.

### *TT tests*

The mean $PO_{axiom}$ during the $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$ was significantly ($p < 0.05$) higher (+ 14.5, 10.9, and 10.8 %, respectively) compared with mean $PO_{SRM}$. The PO differences between Axiom and SRM during the TTs varied from 5 to 13.5 % (from the beginning to the end of the TT). The bias × ÷ random error between Axiom and SRM PO during TTs were 1.115 (95 % CI = 1.116 – 1.173) × ÷ 1.056, 1.095 (95 % CI = 1.070 – 1.121) × ÷ 1.107, and 1.079 (95 % CI = 1.061 – 1.097) × ÷ 1.075, respectively for $TT_{0\%}$, $TT_{3\%}$ and $TT_{6\%}$. It represented absolute PO differences of 43 ± 34, 28 ± 15, and 24 ± 12 W, respectively for $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$. These results signify that the $PO_{axiom}$ was overestimated compared with the $PO_{SRM}$

Table **2** Mechanical variables during TT

| *Conditions* | *Gear ratio* | *Velocity (km/h)* | *$PO_{SRM}$ (W)* | *Axiom slope (%)* | *Corresponding theoretical slope on the field (%)* |
|---|---|---|---|---|---|
| $TT_{0\%}$ | 53/16 | 39.2 | 295 | 0.8 | 0.1 |
| $TT_{3\%}$ | 39/16 | 29.1 | 293 | 3 | 2.4 |
| $TT_{6\%}$ | 39/21 | 22.4 | 310 | 6 | 4.6 |

$PO_{SRM}$: SRM power output, $TT_{0\%}$: Time trial with an Axiom slope of 0.8%, $TT_{3\%}$: Time trial with an Axiom slope of 3%, $TT_{6\%}$: Time trial with an Axiom slope of 6%



and that during TT the Axiom ergometer does not provide a valid PO measurement compared with the SRM.

It is interesting to compare our values of PO differences with results of other validation studies of ergometers compared with the SRM. Balmer et al. [2,3] found PO differences during MAP test and TT between Kingcycle and SRM close to 10% (overestimations of Kingcycle). Millet et al. [14] showed 4 – 7% PO overestimations of the Polar S710 compared to the SRM in their study with different pedalling cadences and exercise intensities. Martin et al. [13] indicated that the PO difference between the Monark and SRM was only 2.36% and they assumed that the SRM was valid compared with the Monark. However, in their study only the error percentage and the correlation coefficient were indicated. Thus, it is not possible to determine if these two devices are reliable. Other studies like Jones and Passfield [11] showed that the bias between SRM and Monark were 1.8%. Van Praagh et al. [21] suggest that the mechanical margin of error in ergometric measurement should be smaller than 5%. That is not the case when the $PO_{axiom}$ is compared with the $PO_{SRM}$ during the MAP test and TT.

There are some effects that could have influenced the PO differences between Axiom and SRM. First, the 5th grade polynomial equation used by the computer programme for PO calculation seems to be dubious. The polynomial equation used in the Axiom software was obtained from $PO_{SRM}$ of a few cyclists using the SRM in the field in a few slopes and with a few different velocities. Using the Martin et al. [13] equation of cyclist motion in the Axiom software could probably increase the validity of the $PO_{axiom}$. Second, inaccurate or incorrect braking regulation could have influenced PO differences between Axiom and SRM. This was revealed during the TTs. Braking torque applied on the Axiom roller decreased according to the time ($r = 0.94$) (Fig. **4**). This could be caused by an increase of temperature of the electromagnetic brake during the TTs due to the Joule-Kelvin effect. This increase could affect the characteristics of the electronic components, like the resistance or coil, and cause the decrease of the Axiom braking resistance. Due to this decrease, the $PO_{axiom}$ increased significantly ($p < 0.05$) according to the time (from 1st to 10th min) whereas the SRM values remained constant (Fig. **5**). The increasing bias was highly correlated with the pedalling cadence (Fig. **3**). This indicates that the cyclists increased their pedalling cadence during TTs from the 1st to the 10th min (+ 5 ± 2 rpm for the three TTs) to maintain a constant PO throughout all the TT. As the Axiom device uses an algorithm based solely on the cadence of the flywheel (velocity of the roller), the $PO_{axiom}$ increases (contrary to the $PO_{SRM}$) when the cyclists increase their pedalling cadence. This phenomenon could partly explain the $PO_{axiom}$ drift. The $PO_{axiom}$ drift could also partially explain the PO differences between Axiom and SRM during the last stage of the MAP test. The $PO_{axiom}$ was beginning to become significantly different only at the fourth stage of the MAP test. Before this stage the $PO_{axiom}$ was close to the $PO_{SRM}$. But above all, the decrease of braking torque in the resistance unit according to time seems to be a major deficiency of the Axiom ergometer.

Third, the Axiom ergometer does not take into account the different energy losses by the friction of the chain. This friction represents between 2 and 4% of the cyclist's PO [13]. An old chain, a bad lubrication, or an incorrect chain alignment can increase the chain friction and thus influence the $PO_{SRM}$. Fourth, in our study the tyre pressure, temperature, and humidity were constant, but it is possible that for a long exercise duration the temperature of the tyres increases due to the friction with the roller of the flywheel, like it was suggested for the Kingcycle ergometer [7,10]. In this case mechanical energy is partially dissipated in caloric energy. That could increase the tyre pressure (Gay-Lussac law) and alter the rolling resistance between the roller and the rear wheel tyre and influence $PO_{SRM}$. Fifth, rotational velocity variations of the Axiom flywheel could have influenced the PO differences between Axiom and SRM. Accelerating the flywheel requires to produce a supplementary work (J) that is not taken into account in the $PO_{axiom}$ measurement but is taken into account in the $PO_{SRM}$. Pedal stroke could be an important cause of these rotational velocity variations. A fluid pedalling pattern will cause slight variations, while a non-fluid pedalling pattern will cause much larger and significant variations of the rotational velocity of the Axiom flywheel. At last, aerodynamic resistance of the rear wheel rotation is not taken into account in the $PO_{axiom}$ calculation. This resistance increases according to the cube of the wheel velocity and influences $PO_{SRM}$. However, this effect is probably negligible.

Like the Kingcycle ergometer, the electromagnetic resistance unit of the Axiom was connected with a roller that was in contact with the rear tyre of the bicycle. Balmer et al. [2] suggested that changes in weight distribution on the bicycle could affect the Kingcycle resistance between the roller and tyre. During TT subjects frequently move on the saddle and in consequence tend to pull forward or sit back [2], respectively reducing or increasing the resistance between rear wheel and Kingcycle roller. This explanation is not valid concerning the Axiom ergometer because on this ergometer the rear wheel was maintained by the wheel's axis via the quick release skewer to the Axiom stand. Thus, the cyclist weight was applied on this axis and not directly on the tyres.

### Validity of Axiom slope simulations

The Axiom slopes simulated during the $TT_{0\%}$, $TT_{3\%}$, and $TT_{6\%}$ were overestimated (Table **2**) compared with the corresponding slopes in the field. These slope overestimations can be attributed to the $PO_{axiom}$ overestimations, mainly due to the 5th grade polynomial equation used by the Axiom computer programme and inaccurate or incorrect braking regulation. Incorrect braking adjustments of the Axiom ergometer concerning slope simulations were previously detected during preliminary tests. There were no braking adjustments for programmed slopes in the Axiom computer programme that exceeded 6%. At programmed slopes close to 6%, the maximal braking force is reached and the resistance unit becomes saturated. This means that the Axiom cannot simulate field slopes of approximately 6% and higher. So we can conclude that the Axiom ergometer can only be used to simulate race profiles with field slopes lower than 6% and that a correction in slope has to be made for slope-input in the Axiom computer programme.

### Reliability of $PO_{axiom}$

The mean CV in PO for each stage of MAP test was 4.1% and 2.2%, respectively for the SRM and Axiom. This result indicates that the Axiom is a reliable powermeter and that brake adjustment in the resistance unit is reproducible. Balmer et al. [3] showed a mean CV for the Kingcycle ergometer during a MAP test close to the Axiom value, namely 2.0%. The Axiom CV is also comparable to the Polar S710 CV (2.2%) obtained during a TT of 6 min duration [14].

The high reliability of the Axiom ergometer indicates that it can be used to evaluate training adaptations, since comparisons of similar sessions is possible. When the $PO_{axiom}$ drift according to the time is taken into account, it is possible to use corrective equations (Fig. **2**). The conditions for obtaining reliable $PO_{axiom}$ measurements are the standardisation of 1) the model and the pressure of the tyre and 2) the pressure between the Axiom roller and the rear wheel tyre.

Future research concerning the Axiom ergometer could investigate the validity and reliability of the Axiom for 1) high PO values (interesting for performing force-velocity tests) and 2) a long duration of use (interesting for simulating real road cycling races lasting several hours).

## Conclusion

The results of this study indicate that the Axiom ergometer does not provide a valid PO measurement compared with the SRM system. The Axiom ergometer should not be used to perform scientific research. However, the Axiom ergometer is a highly reliable powermeter. It can be used for relative PO comparisons with competitive cyclists during a race season or to perform simulations of race profiles with slopes up to 5%, when slope corrections are made.

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