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Gross Efficiency and Cycling Economy Are Higher in the Field as Compared with on an Axiom Stationary Ergometer

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This study was designed to examine the biomechanical and physiological responses between cycling on the Axiom stationary ergometer (Axiom, Elite, Fontaniva, Italy) vs. field conditions for both uphill and level ground cycling. Nine cyclists performed cycling bouts in the laboratory on an Axiom stationary ergometer and on their personal road bikes in actual road cycling conditions in the field with three pedaling cadences during uphill and level cycling. Gross efficiency and cycling economy were lower (–10%) for the Axiom stationary ergometer compared with the field. The preferred pedaling cadence was higher for the Axiom stationary ergometer conditions compared with the field conditions only for uphill cycling. Our data suggests that simulated cycling using the Axiom stationary ergometer differs from actual cycling in the field. These results should be taken into account notably for improving the precision of the model of cycling performance, and when it is necessary to compare two cycling test conditions (field/laboratory, using different ergometers).

Keywords: road cycling, biomechanics of pedaling, pedaling cadence, crank inertial load

The majority of studies focusing on determinants of cycling performance have been performed under laboratory conditions. In these conditions, the effect of different training programs, pacing strategy, pedaling cadence (PC), position on the bicycle, pedaling technique are evaluated in standardized procedures. Despite some methodological advantages, the shortcomings of this approach are that they may not represent actual cycling in the field, thus reducing their relevance. Therefore, the validity of the observations obtained in the laboratory conditions is fundamental to apply these results to outdoor cycling.

The difference between the laboratory and road cycling are not well documented or the results are sometimes contradictory. Contrary to Bertucci et al. (2005a), Gardner et al. (2007) suggested that the sprint performance in the field is consistent with the laboratory tests. Others have shown that time trial performance is better (+5% of cycling speed) in the laboratory (Jobson et al., 2007; Smith et al., 2001). Kenny et al. (1995) have shown that the relationships between heart rate and oxygen consumption (VO_2) are altered in the laboratory finding that the VO_2 for a given heart rate was significantly lower in the field compared with the laboratory conditions.

Several studies have shown that a difference in crank inertial load (CIL) can alter the biomechanical (crank profile torque, preferred PC, gross efficiency) or physiological measurement outcomes (Fregly et al., 1996; Hansen et al., 2002a, 2002b; Bertucci et al., 2005b, 2007). Due to different gear ratios and inertia of the flywheel, the cycling ergometers used in the laboratory generate different ranges of CIL (Fregly et al., 2000).

Anecdotally, the differences of performance between the laboratory and the field conditions are also reported by several coaches of professional cycling teams (Cofidis, FDJ) using the power output measurements to optimize the training protocols. They have observed that the performances measured during laboratory conditions on home trainers are generally lower by 30–50 W during time trial of 20 min compared with the training tests in outdoor conditions (especially in uphill).

Thus, the aim of this study is to determine if the laboratory cycling simulations of level and uphill cycling performed on an Axiom stationary ergometer (Elite, Fontaniva, Italy) is representative of the actual cycling in the field in terms of preferred PC, cycling economy (CE) and gross efficiency (GE). We hypothesized that preferred PC, CE and GE will be affected by the stationary ergometer conditions compared with the road cycling.

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Methods

Nine male cyclists (age: 24.9 ± 1.3 years, height: 1.76 ± 0.05 m, body mass: 69.8 ± 6.1 kg, VO_{2max}: 68.2 ± 2.5 $mL \cdot min^{-1} \cdot kg^{-1}$) volunteered for this study. They were well-trained cyclists at the time of the study, as evidenced by relatively high VO_{2max} values, and had been competing at regional and/or national levels for 5 ± 2 years. All subjects were informed of all testing procedures, protocols, risks, benefits, and time commitment before participating and voluntarily provided informed, written consent. The study was approved by the local institutional ethics committee (University of Franche-Comte).

Special attention has been focused on the quality of the physiological and mechanical measurements. We have used a SRM crank powermeter (SRM Training System scientific model Schoberer, Germany) using 20 strain gauges validated previously by Jones and Passfield (1998) to perform the power output and PC measurements (10 Hz). Before the current study we performed the static calibration described by Wooles et al. (2005) in attempt to determine the actual slope between the frequency data and the torque value given by the SRM (calibration factor). However, to minimize the possible difference between different devices, we have used the same SRM powermeter in all study conditions. According to the manufacturer's recommendations, before each test session of each cyclist, we calibrated the offset value of the SRM.

At the beginning of the study, the cyclists performed an incremental test on a Monark ergometer (818 E, Stockholm Sweden), which was fitted with the SRM. The Monark was also equipped with a race saddle, "clipless" pedals, and adjustable race handlebars to allow each cyclist to perform the test in his usual cycling position. All of the other laboratory tests were performed on each subject with their own bicycle, fitted with the SRM, which was connected to the stationary Axiom ergometer (Elite, Fontaniva, Italy). The Axiom is an electromagnetically braked computerized ergometer (Figure 1). By fixing the rear wheel in the stand of the ergometer by the rear wheel quick release skewer, lateral motion of the bicycle is prevented, and this system has the distinct advantage that cyclists can use their own bicycle (Bertucci et al., 2005c). This is particularly important for this study to be able to standardize the bicycle for both field and laboratory conditions and remove this source of variability. In this condition the power output was measured with the SRM fitted on the subject's bike.

During the outdoor tests, each cyclist used his own bike with the SRM exactly as done for the laboratory tests.

During each laboratory and field test the cardiorespiratory variables (VO_2 and carbon dioxide output (VCO_2, $L \cdot min^{-1}$) were measured (averaged over 15 s) with the same breath-by-breath telemetric and portable gas analyzer device (K4b^2, Cosmed, Rome, Italy). The K4b^2 has been previously used by numerous researchers for different types of locomotion such as swimming (Bentley et al., 2005), running (Billat et al., 2009; Castagna et al., 2007; Duffield et al., 2004a) and outdoor cycling (Millet et al., 2002). The K4b^2 gas analyzer device has been previously validated (Hausswirth et al., 1997, McLaughlin et al., 2001, Pinnington et al., 2001, Duffield et al., 2004b, Schrack et al., 2010). The pneumotachograph and analyzers of the K4b^2 were calibrated before each test session according to the manufacturer's specifications. During the outdoor tests, the wind velocity was measured with an anemometer (Jules Richard, Argenteuil, France; accuracy of ±2%). Trials were not performed or were excluded if mean wind velocity exceeded 3.0 $m \cdot s^{-1}$. In the laboratory and outdoor conditions, the range of temperature was between 20 and 22 °C.

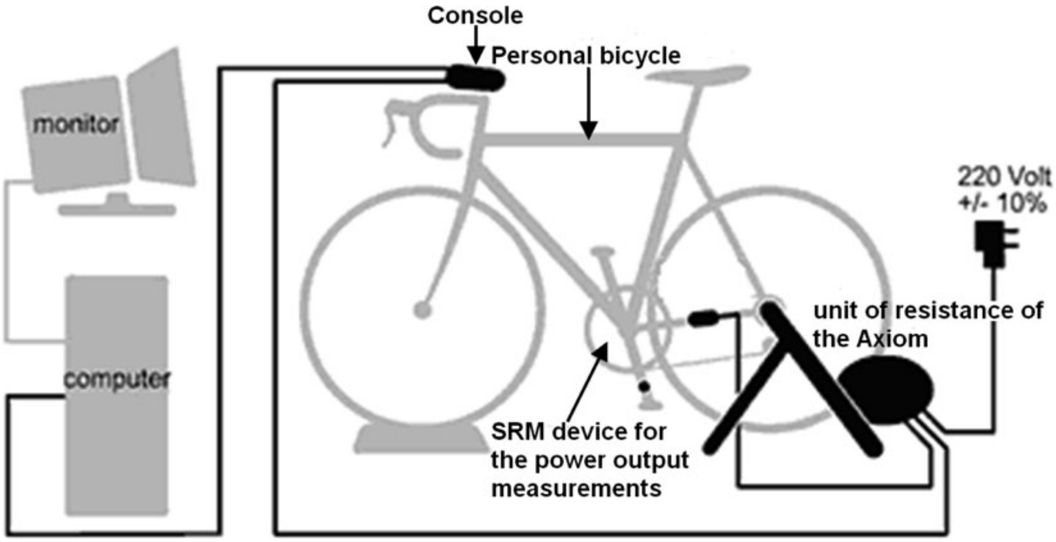

Figure 1 — Laboratory conditions with the Axiom device fitted with a personal bicycle of each cyclist.

Test Protocols

The cyclists were instructed to not perform high-intensity exercise the day before the beginning of the experimentation. The protocol of the present experimentation was performed during three test days. There were at least two days between each test day. On the first test day, subjects performed a continuous incremental test on the Monark ergometer to determine maximal oxygen uptake (VO_{2max}), ventilatory threshold (VT) and peak power output. The two other test sessions in the laboratory and in the field were performed in a randomized order. During these two test sessions, the order of the six different exercises (three different PC on uphill and level conditions) for each session was also randomized.

On the first test day, the incremental test consisted of a 4 min baseline at 90 W, after which, the power output was increased by 30 W every minute until voluntary exhaustion or when the subjects were no longer able to maintain ± 5 rpm of the required PC (90 rpm). The value for VO_{2max} was defined as the highest VO_2 averaged over 30 s throughout the test. Peak power output was determined as the highest power output that was maintained for at least 30 s during the incremental test. The VT was identified by visual inspection by two researchers from the breakpoints of the ventilatory equivalent for oxygen ($VE{\cdot}VO_2^{-1}$) and for carbon dioxide ($VE{\cdot}VCO_2^{-1}$) plotted against VO_2 (Poole and Gaesser, 1985). The average of the two independent determinations was taken to be VT. When VT identification differed by more than 10%, the help of a third researcher was sought (Mora-Rodriguez & Aguado-Jimenez, 2006). Ninety-percent of the VO_2 at VT was determined, and a corresponding power output was calculated from the VO_2 vs. power output linear regression.

The experimental protocol in the field was composed of three tests on level terrain and three tests on uphill terrain (4.8% grade). All tests were performed in the seated position at a power output representing 90% of VT (238 ± 16 W, 78 ± 6% of VO_{2max}) to be sure that the cyclists perform the exercise at high intensity just under the VT. The preferred PC was determined after a 15 min warm-up phase, by the cyclist, by self-selecting a gear ratio that they preferred while cycling at the required power output (90% of VT) in each of the two conditions (level and uphill terrain). Each cycling trial lasted 5–7 min and the data used for the analysis were collected after 3 min from the beginning of the test to ensure that a VO_2 steady state was achieved (verified by no change in VO_2 between 3 min and the end of the test). There was at least 5–10 min of active recovery (30–40% of peak power output) between the trials. The cyclists were able to see and control their required power output using the screen display of the SRM power control; however, they were blinded to the actual cadence. One test was performed in level and uphill cycling with the preferred gear ratio (LP and UP, respectively), the two other tests with a gear ratio above (LH and UH) and below (LL and UL) the preferred gear ratio. These three tests for each experimental condition (uphill and level) were performed in randomized order.

The similar experimental protocol was performed in the laboratory conditions with the Axiom ergometer. During all the laboratory tests, the subjects were cooled by an electric fan. The Axiom was programmed using the ergometer software to simulate pedaling resistance of level ground (LL, LP, LH) and of uphill conditions with a slope of 4.8% (UL, UP, UH). In the software, the breaking force was determined from the polynomial regression determined by the manufacturer (Elite s.r.l.) including notably the mass of the cyclist and the slope of the road.

With the same instructions as the field test sessions, the cyclists were instructed to choose their preferred gear ratio while cycling at the required power output in both level and uphill simulations. The resultant PC was recorded as their preferred PC. To simulate the body position on a climb, the front wheel of the bicycle was inclined to represent an inclination corresponding to a slope of 4.8% in the field.

Measured and Calculated Variables

In the road cycling, the CIL ($kg{\cdot}m^2$) was calculated following the methods of Hansen et al. (2002a, 2002b). In the laboratory condition, the CIL was computed from the methods previously used (Fregly et al., 2000; Duc et al., 2005; Edwards et al., 2007; Gardner et al., 2007).

Gross efficiency (GE, %)—defined as the ratio of the power output (W) to the metabolic power (total energy expended according to the time) (W)—was calculated for each cycling condition. GE was calculated from measures of metabolic power, VO_2 ($L{\cdot}min^{-1}$), VCO_2 ($L{\cdot}min^{-1}$), and power output during steady state conditions of each trial. The metabolic power was determined as described in Faria et al., (2005) from Brouwer's equation.

GE (%) was determined using the following equation:

$$GE = (\text{power output}/\text{metabolic power}) \times 100$$

The cycling economy (CE, $W{\cdot}LO_2^{-1}{\cdot}min^{-1}$) was defined as the ratio of the power output (W) to the oxygen consumption ($LO_2{\cdot}min^{-1}$) (Faria et al., 2005).

Statistics

Assumptions of normality were verified using the Kolmogorov–Smirnov test. To analyze the differences between the experimental conditions, intrasubject comparisons were performed using a two-way ANOVA (pedaling condition; field vs. Axiom stationary ergometer, and slope; level vs. uphill) on the GE, CE, oxygen consumption, preferred PC and power output. If significant differences were detected, we completed the analyses by the matched pairs *t* test. In this case we take into account the increasing risk of the type I error by a progressive adjustment of the critical alpha level based notably on the number of comparisons and the alpha level desired (Knudson, 2009). For all statistical analyses (Statistica 7.1.30, Statsoft), effect sizes (ES) were computed as

Cohen's *d* to assess the magnitude of the differences in mean scores that appeared to be statistically significant. The power of the statistical analyses were calculated with the G*Power (version 3.0.10) software. A Pearson correlation coefficient was calculated to determine the relationships between (1) all the GE and the CIL values and (2) the preferred PC and the CIL values in the field and in the Axiom stationary ergometer.

Main Abbreviations Used

CIL: Crank inertial load ($kg \cdot m^2$)
LL: Level terrain at low pedaling cadence
LP: Level terrain at preferred pedaling cadence
LH: Level terrain at high pedaling cadence
UL: Uphill terrain at low pedaling cadence
UP: Uphill terrain at preferred pedaling cadence
UH: Uphill terrain at high pedaling cadence
PC: Pedaling cadence (rpm)
VT: Ventilatory threshold
VO_2: Oxygen consumption
VCO_2: Carbon dioxide rejection
RER: Respiratory exchange ratio

Results

The mean wind during outdoor tests was negligible (1.2 ± 0.3 $m \cdot s^{-1}$). No wind condition exceeded 3.0 $m \cdot s^{-1}$ during the tests and thus no trial was excluded.

The preferred PC was lower for uphill cycling in the field compared with the uphill cycling on the stationary ergometer (p = .016, ES: 1.14, statistical power: 0.71). For field cycling, the preferred PC was significantly lower for uphill cycling compared with level cycling (p = .003, ES: 1.70, statistical power: 0.87). There was a difference in preferred PC between level and uphill cycling in the stationary ergometer (p = .046, ES: 0.98, statistical power: 0.66).

The ANOVA analysis indicates a significant effect ($p < .01$) of the pedaling conditions (field vs. Axiom stationary ergometer) for GE, EC and the oxygen consumption (Table 1 and 2).

GE and CE were higher (+12% and +11%) in the field conditions compared with the stationary ergometer conditions (Tables 1 and 2), with large ES values (range of –1.41 to –1.90 and –1.18 to –1.78, respectively). Except for the UP condition, the VO_2 was lower (–9%) in the field compared with the stationary ergometer (ES range of 1.22–1.66).

Table 1 Mean ± *SD* for pedaling cadence, power output, oxygen consumption, heart rate, gross efficiency and cycling economy for uphill cycling in the laboratory and in the field

Laboratory and Field Conditions	Pedaling Cadence (rpm)	Power Output (W)	VO_2 ($mLO_2 \cdot min^{-1}$)	Heart Rate (bpm)	GE (%)	CE ($W \cdot LO_2^{-1} \cdot min^{-1}$)
Laboratory UL	83 ± 7	239 ± 16	3820 ± 223	155 ± 11	17.7 ± 1.1	63 ± 4
Field UL	73 ± 12[a]	245 ± 12	3442 ± 316[a]	149 ± 10	20.3 ± 1.6[a]	72 ± 7[a]
Laboratory UP	90 ± 6	241 ± 17	3806 ± 232	154 ± 12	17.8 ± 1.2	64 ± 5
Field UP	80 ± 12[a]	247 ± 15	3596 ± 332	155 ± 10	19.4 ± 1.1[a]	69 ± 6[b]
Laboratory UH	97 ± 8	239 ± 17	3889 ± 326	157 ± 12	17.3 ± 1.2	62 ± 5
Field UH	86 ± 14[a]	243 ± 15	3554 ± 250[a]	153 ± 11	19.3 ± 1.2[a]	69 ± 5[a]

Note. GE: Gross efficiency. CE: Cycling economy. VO_2: oxygen consumption. UL: Uphill terrain at low pedaling cadence. UP: Uphill terrain at preferred pedaling cadence. UH: Uphill terrain at high pedaling cadence.

[a] Significantly ($p < 0.05$) different from the laboratory conditions.

[b] Tendency to be significantly ($p < 0.08$) different from the laboratory conditions.

Table 2 Mean ± *SD* of pedaling cadence, power output, oxygen consumption, heart rate, gross efficiency and cycling economy for level cycling in the laboratory and in the field

Laboratory and Field Conditions	Pedaling Cadence (rpm)	Power Output (W)	VO_2 ($mLO_2 \cdot min^{-1}$)	Heart Rate (bpm)	GE (%)	CE ($W \cdot LO_2^{-1} \cdot min^{-1}$)
Laboratory LL	87 ± 7	239 ± 18	3759 ± 179	154 ± 12	18.1 ± 1.1	64 ± 4
Field LL	87 ± 7	240 ± 17	3397 ± 401[a]	148 ± 9	20.6 ± 1.6[a]	71 ± 7[a]
Laboratory LP	95 ± 5	239 ± 18	3786 ± 233	155 ± 13	17.8 ± 1.1	64 ± 4
Field LP	96 ± 8	240 ± 19	3456 ± 314[a]	156 ± 8	19.6 ± 1.5[a]	70 ± 7[a]
Laboratory LH	103 ± 5	240 ± 17	3965 ± 272	158 ± 12	17.3 ± 1.2	62 ± 4
Field LH	104 ± 9	237 ± 18	3451 ± 384[a]	154 ± 12[a]	19.5 ± 1.9[a]	70 ± 7[a]

Note. GE: Gross efficiency. CE: Cycling economy. VO_2: oxygen consumption. LL: Level terrain at low pedaling cadence. LP: Level terrain at preferred pedaling cadence. LH: Level terrain at high pedaling cadence.

[a] Significantly ($p < 0.05$) different from the laboratory conditions.

The CIL values for the different experimental conditions for the stationary ergometer and road cycling are indicated in Table 3. Figure 2 shows GE values according to the CIL in the stationary ergometer and field conditions (level and uphill) for each cyclist. The correlation relationships between the CIL and GE values were significant ($r = .40$, $p < .001$, GE = 0.025 CIL + 17.5). Figure 3 shows the correlation between the preferred PC and CIL values in the field conditions (level and uphill) for each cyclist. The correlation relationships between the preferred PC and CIL values tend to be significant ($r = .44$, $p = .06$, preferred PC = 0.2007 CIL + 75.4). However, the correlation between the preferred PC and CIL values with the Axiom stationary ergometer (level and uphill) was not significant ($r = .31$, $p = .21$, preferred PC = 0.144 CIL + 87.8).

Table 3 Mean crank inertial load in laboratory and road cycling conditions

Cycling Conditions	Laboratory Crank Inertial Load (kg·m^2)	Field Crank Inertial Load (kg·m^2)
UL	18 ± 4	43 ± 11
UP	17 ± 4	36 ± 8
UH	15 ± 3	31 ± 7
LL	45 ± 5	106 ± 16
LP	40 ± 5	88 ± 10
LH	36 ± 4	73 ± 8

Note. UL: Uphill terrain at low pedaling cadence, UP: Uphill terrain at preferred pedaling cadence, UH: Uphill terrain at high pedaling cadence, LL: Level terrain at low pedaling cadence, LP: Level terrain at preferred pedaling cadence, LH: Level terrain at high pedaling cadence.

Discussion

The most important finding of this study is that for the same power output, GE and CE during level and uphill cycling were higher (+12 and +11%, respectively) during cycling in the field compared with simulated laboratory conditions on the Axiom stationary ergometer with their personal bike. These results suggest that the GE and the CE were affected by the laboratory conditions in Axiom stationary ergometer. Our results suggest that with the same VO_2 consumption used in the laboratory, the cyclist could generate higher power output (close to 10%) in the field compared with the Axiom stationary ergometer conditions. This hypothesis is not in line with Quod et al. (2010), who have shown a similar power profile in the laboratory and in the race. Quod et al. (2010) have performed PO measurements from 5 s to 10 min; thus, the exercises have been performed at high intensity. These intensities were higher than the anaerobic threshold or the critical power (Vanhatalo et al., 2011). The GE and CE must be measured with an oxygen consumption steady state. Thus, the results of Quod et al. (2010) could not be explained in major part by the GE variable. It is possible that the GE is different between the laboratory and the race in Quod et al. (2010) study. In addition, in the last study, the PC are different for the same PO in the laboratory compared with the race conditions. These differences could alter the GE (Ettema & Loras, 2009; Lucia et al., 2004). Unfortunately, these last authors have not measured the GE. It would be very interesting in furthers studies to analyze the power profile with GE measurements in the laboratory and road cycling conditions.

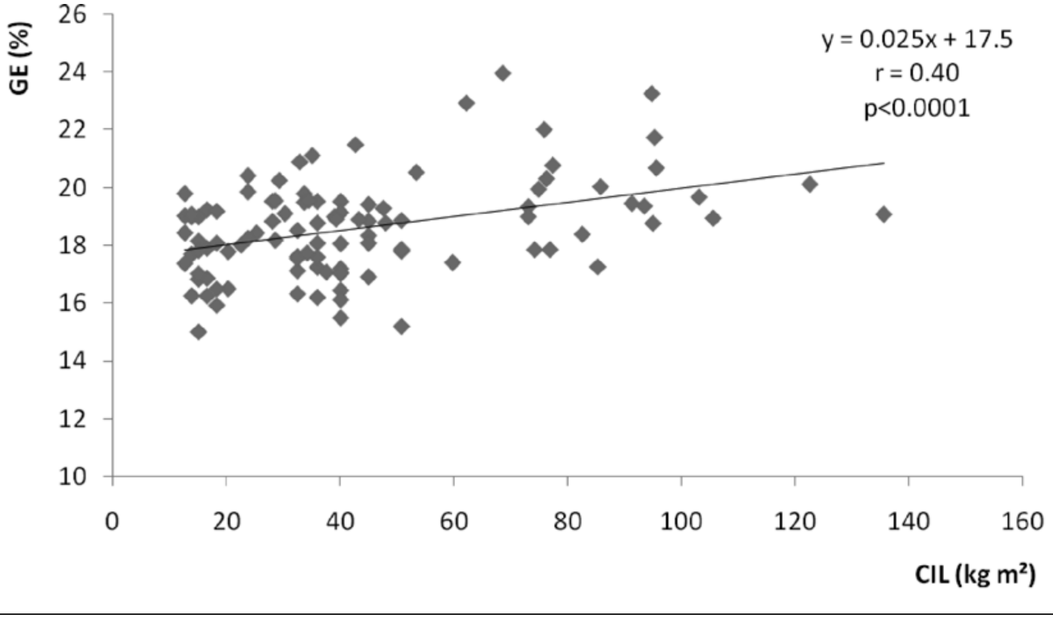

Figure 2 — Gross efficiency (GE) values according to the crank inertial load (CIL) in the stationary ergometer and field conditions (level and uphill) for each cyclist.

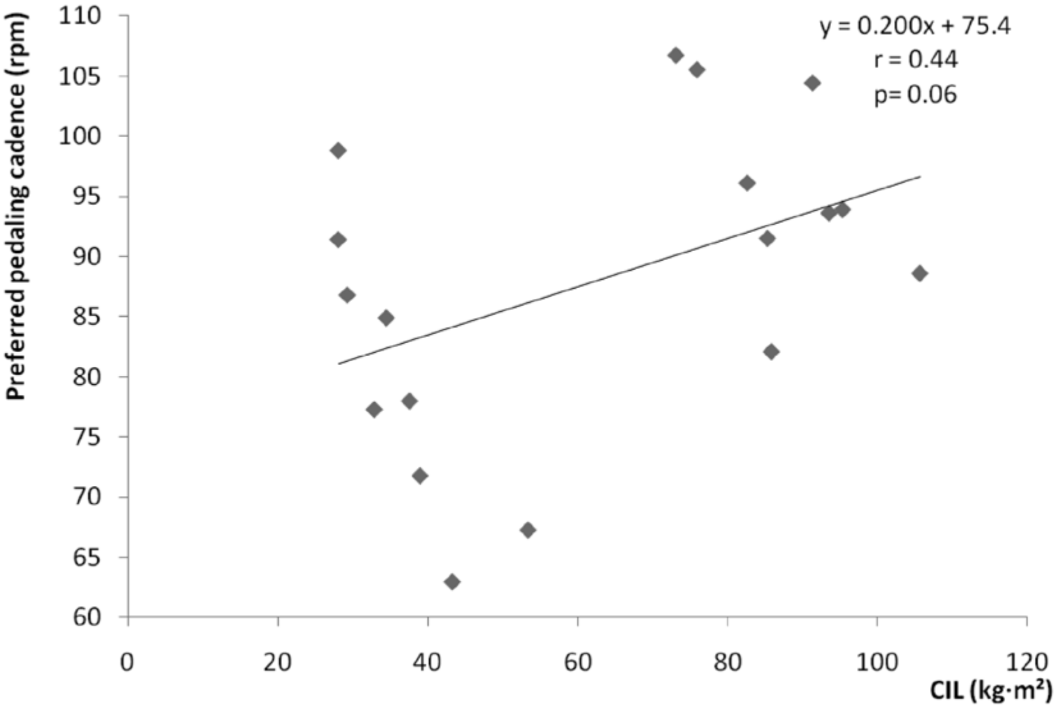

Figure 3 — Correlation between the preferred pedaling cadence and crank inertial load (CIL) values in the field conditions (level and uphill) for each cyclist.

The lower CE and GE observed for the Axiom stationary ergometer is associated with a lower CIL (–54%) compared with the field (Table 3). Jobson et al. (2008) observed that during a time trial in an aerodynamic posture, cyclists generated a higher power output in the road compared with the laboratory with similar VO_2. In their study, the Kingcycle ergometer has a lower CIL compared with road cycling CIL (–50%). Kenny et al. (1995) have shown that laboratory cycling resulted in higher VO_2 compared with field cycling. These authors suggest that the differences in balance, maintenance, and inertial ergometer characteristics on the laboratory apparatus had a significant effect on the cycling mechanics and altered the VO_2. Voigt and Kiparski (1989) have found that the load sum pulse could be altered by the inertial characteristics of the ergometer. They suggest that the changes in physiological demands could be explained by jerking movements of the legs during pedaling, due to insufficient ergometer CIL. Our results (Figure 2) show that there is a significant ($p < .001$) correlation ($r = .40$) between the CIL and the GE. These results suggest that lower CIL conditions increases the physiological demands for a given power output and thus could explain a lower GE compared with higher CIL conditions. However, this conclusion should be interpreted with caution because the determination coefficient of variation is very low ($r^2 = .16$) indicating that the CIL variation explains only 16% of the variation of GE. The analyses of our results (Tables 1, 2 and 3) show for similar CIL using the stationary ergometer and in the field (LL in the stationary ergometer vs. UL in the field and LH in the stationary ergometer vs. UP in the field) that the GE is significantly different. These results suggest that the CIL is not the major factor explaining the GE differences between the Axiom stationary ergometer and the field. These results are not in accordance with Hansen et al. (2002a) who have shown on untrained subjects that at 250 W in the laboratory the GE was higher in the condition with low CIL value (ES: 0.5). It is possible that CIL variation elicits different responses according to the level of training of the cyclists (Edwards et al., 2007).

The characteristics of the ergometer used in the current study could explain in part the difference between the laboratory and the field conditions. Duc et al. (2006, 2008) have shown that the muscular activity was higher with the Axiom ergometer compared with the similar cycling exercise performed on the motorized treadmill at the same power output. These results likely explain the alteration of VO_2 consumption, GE and CE in the laboratory conditions in our study. Cannon et al. (2007) have already shown that an alteration of the muscular activation can modify the GE. The maximal tilt angles of the bicycle in uphill standing pedaling on the treadmill are between 8–11° for a slope between 4–10% (Duc et al., 2008). In addition, with the Axiom device the bicycle lateral sways were constrained and thus the cyclists cannot perform the habitual bicycle side-to-side motion observed in the field conditions (especially in the uphill conditions for the standing position). It is possible that the bicycle lateral sways can allow a better force orientation on the pedal and thus an optimization of GE and CE. This hypothesis could be verified using a dynamometric pedal to allow the measurement of the pedal force orientation. Bertucci et al. (2005a) have previously shown that the performance during sprint tests can be altered if the bicycle lateral sways are constrained.

Our results show that the effect of CIL variation on the preferred PC values was different for the Axiom stationary ergometer compared with the road cycling conditions (Table 1 and 3). For the stationary ergometer, the relation between the CIL and the preferred PC was not significant. However, in the field, the correlation between the CIL and preferred PC tended to be significant (preferred PC = 0.2007CIL + 75.4, $r = .44$, $p = .06$) (Figure 3). These results suggest that the conditions of pedaling (Axiom stationary ergometer vs. field) could alter the CIL effect on the preferred PC values. These results suggest that the preferred PC must be affected by other factors in addition to the CIL variation. Our results in the field are in accordance with Hansen et al., (2002a), who have shown that for cycling on a treadmill, the preferred PC varies with CIL, and that a lower preferred PC is a result of lower CIL. These results suggest that in the laboratory, the CIL effect on the preferred PC is likely different for treadmill cycling compared with the Axiom stationary ergometer. Sassi et al. (2009) have shown during road cycling with varying slopes, that the preferred PC is correlated with the CIL such that as the slope of the terrain increases, CIL decreases and the preferred PC also decreases. It is worthwhile to note that they also found cycling velocity to affect the preferred PC, although there was a tendency for the preferred PC to be lower during uphill cycling. We found a difference in preferred PC between level and uphill cycling in the field (96 ± 8 vs. 80 ± 12 rpm), with a 60% lower CIL in the uphill condition. Our results confirm the key role of the CIL on the preferred PC in the field conditions when the slope of the road was modified.

Many studies have shown that the PC can alter the GE. Recently, the review by Ettema and Loras (2009) reported a clear negative effect of PC on GE. They indicated that about 91% of all variance in energy expenditure can be explained by work rate, with about 10% being explained by the PC. Lucia et al. (2004) have shown that for professional cyclists, GE was lower at 60 rpm compared with 100 rpm (22.4 ± 1.7 vs. 24.2 ± 2.0%, respectively). However, there is no difference between 80 and 100 rpm. In our study in uphill conditions, the mean PC difference between the Axiom stationary ergometer and the field conditions was close to 10 rpm. Thus, we think that the different PC observed in the uphill conditions cannot be the major explanation of the CE and GE differences between the Axiom stationary ergometer and road cycling. Several studies (Millet et al., 2002; Harnish et al., 2007) in well-trained athletes have shown no difference in VO_2 or in CE when the PC increased. Moreover, the PC effect cannot explain the GE and CE differences for the level condition since no difference in PC was observed between field and laboratory tests.

Further experimentation must be performed to verify if the GE and CE were altered (compared with the field conditions) on other ergometers in the same proportion as with the Axiom stationary ergometer. This experimentation could allow insight into the external validity of the present results. The GE values obtained in the laboratory conditions in the current study (17.3–18.4%) are relatively close to the GE values obtained by Moseley et al. (2004) (17.9–18.9%) on 69 cyclists (from recreational to elite level). In our study the cyclists have used their personal bicycles in the laboratory on the Axiom stationary ergometer and in the field, which to our knowledge is the only the case in which the same (and personal) bikes were used, when comparing this study to other cycling studies (Millet et al., 2002; Jobson et al., 2007; Sassi et al., 2009). We believe this is an important strength of this study in that we have normalized a number of factors related to body position, posture, familiarity with the bicycle for both laboratory and field testing, thus minimizing confounding variables that may relate to the outcome measures of PC, GE and CE.

In conclusion, our results suggest that the CE, GE, and preferred PC were different in the laboratory conditions on the Axiom stationary ergometer compared with actual road cycling conditions, notably for cycling uphill. Our results suggest that the laboratory conditions on an Axiom stationary ergometer could underestimate the cycling performance (power output) at submaximal intensity compared with the field. It appears very important to know the relationships between the performance in the laboratory and in the field. It is probable that this relationship was reproducible and thus allows a valid prediction of performance. These results should be taken into account notably for the training intensity prescriptions calculated from laboratory investigations.

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