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# Level ground and uphill cycling efficiency in seated and standing positions

GRÉGOIRE P. MILLET, CYRILLE TRONCHE, NICOLAS FUSTER, and ROBIN CANDAU

UPRES-EA 2991 "Sport, Performance, Santé," Faculté des Sciences du Sport, Montpellier, FRANCE

## ABSTRACT

MILLET, G. P., C. TRONCHE, N. FUSTER, and R. CANDAU. Level ground and uphill cycling efficiency in seated and standing positions. *Med. Sci. Sports Exerc.*, Vol. 34, No. 10, pp. 1645–1652, 2002. **Purpose:** This study was designed to examine the effects of cycling position (seated or standing) during level-ground and uphill cycling on gross external efficiency (GE) and economy (EC). **Methods:** Eight well-trained cyclists performed in a randomized order five trials of 6-min duration at 75% of peak power output either on a velodrome or during the ascent of a hill in seated or standing position. GE and EC were calculated by using the mechanical power output that was measured by crankset (SRM) and energy consumption by a portable gas analyzer (Cosmed K4b<sup>2</sup>). In addition, each subject performed three 30-s maximal sprints on a laboratory-based cycle ergometer or in the field either in seated or standing position. **Results:** GE and EC were, respectively,  $22.4 \pm 1.5\%$  (CV = 5.6%) and  $4.69 \pm 0.33 \text{ kJ}\cdot\text{L}^{-1}$  (CV = 5.7%) and were not different between level seated, uphill seated, or uphill standing conditions. Heart rate was significantly ( $P < 0.05$ ) higher in standing position. In the uphill cycling trials, minute ventilation was higher ( $P < 0.05$ ) in standing than in seated position. The average 30-s power output was higher ( $P < 0.01$ ) in standing ( $803 \pm 103 \text{ W}$ ) than in seated position ( $635 \pm 123 \text{ W}$ ) or on the stationary ergometer ( $603 \pm 81 \text{ W}$ ). **Conclusion:** Gradient or body position appears to have a negligible effect on external efficiency in field-based high-intensity cycling exercise. Greater short-term power can be produced in standing position, presumably due to a greater force developed per revolution. However, the technical features of the standing position may be one of the most determining factors affecting the metabolic responses. **Key Words:** ECONOMY, MECHANICAL POWER, OXYGEN CONSUMPTION, VENTILATION

Efficiency has been described as the ratio of work accomplished to energy expended (8). Cycling efficiency has been shown to be dependent on different parameters such as pedaling cadence (8), bike set-up, body position (24), muscle fiber type (5), or the methodology used to determine these variables (8). Several procedures for the calculation of the efficiency have been proposed, mainly differentiated by a baseline correction factor that is used to correct the estimate of the energy expenditure and therefore of the measured level of efficiency (8). Gross efficiency (GE) is defined as the ratio of the work completed to the total energy expended. Net efficiency (NE) and work efficiency (WE) have for baseline the resting metabolic rate (RMR) and the energy required by unloaded cycling, respectively. Because it is thought that the baseline metabolic rate is not constant during exercise, delta efficiency (DE) was defined as the ratio between the delta of work accomplished to the delta of energy expended (8). Although GE takes into account changes in both substrate utilization and external power output, GE is a poor measure of the work efficiency (27). Nevertheless, GE is known to influence cycling performance, because the average power output over 1 h (342 vs 315 W) was better in a group with a high GE (21.9%) compared with a group with a lower GE

(20.4%) (10). Furthermore, the change in GE has been demonstrated to be related to the change in cycling performance, because the decrease in GE (from 22.6% to 20.7%) was highly correlated ( $r = 0.91$ ) with the decrease in performance after 1-h moderate endurance cycling exercise (23). GE was also shown recently to have a lower variability (CV = 4.2%) than DE (CV = 6.7%) over three incremental ergometer tests (21). Therefore, GE represents a variable that detects smaller changes in exercise efficiency over several trials.

The results regarding the effects of change in body position (i.e., seated vs standing) on energy expenditure, heart rate (HR), or pulmonary ventilation ( $\dot{V}E$ ) in cycling are varied (20,24,28–29). For example, an increase in the oxygen consumption ( $\dot{V}O_2$ ), HR, and  $\dot{V}E$  has been reported (24,29) or not (20,28) in a standing position, when compared with a seated position. These previous studies were conducted using treadmill cycling where velocity and pedaling cadence were restricted during each exercise trial. However, the physiological responses in field exercise may differ when compared with laboratory-based tests (7). For example, laboratory-based tasks such as cycling ergometry or treadmill cycling may change the mechanical characteristics of the activity, leading to a different metabolic response when compared with field-based cycling, therefore altering the work efficiency (14).

To the best of our knowledge, the influence of the body position on external efficiency and economy during field-based cycling locomotion has not been investigated. Therefore, the purpose of the present study was to identify the effects of a change in the gradient (i.e., level ground or

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uphill) and body position (i.e., seated or standing) on external efficiency and economy in cycling with well-trained cyclists.

## METHODS

**Subjects.** Eight male cyclists ranging from regional to professional level volunteered to take part in this experiment. All subjects were well trained at the time of the experiment, which was conducted at the beginning of their competition period. The study was approved by the institutional ethics committee, and all subjects provided written, voluntary, informed consent before participation. The main individual characteristics of the subjects are presented in Table 1.

**Experimental design.** The study comprised four testing sessions separated by a maximum of 4 d: 1) The subjects performed an incremental test to exhaustion on a cycle ergometer to determine the peak power output (PPO). 2–3) On two consecutive days, the subjects then performed in a randomized order five field trials of 6-min duration at a constant power (75% of PPO). 4) On a separate occasion, the subjects performed three maximal sprints of 30-s duration for determination of the anaerobic power. Each test session was performed at the same time of the day ( $\pm 1$  h), and subjects were directed to arrive fully rested and to have refrained from consuming caffeine and alcohol during the experimental period.

**Incremental test to exhaustion.** A friction-loaded cycle ergometer (Monark 818 E, Stockholm, Sweden) equipped with racing saddle, drop handlebars, and clip-in pedals was used for the incremental exercise test. After 6 min of standardized warm-up at 50–60 W, the initial workload was set at 100 W and was increased by 30 W·min<sup>-1</sup>. The pedaling cadence was maintained constant at 70 rpm through the test with a metronome. The test was carried out until the subjects could no longer maintain the required cadence. The peak power output (PPO) was determined as the highest workload fully completed.

**Field testing.** The subjects performed on two consecutive days either two level-ground cycling trials in a seated position on a velodrome or three uphill-cycling trials. Two of the uphill trials were performed in a seated position and one in a standing position. The uphill trials were completed on a hill with a constant gradient of 5.3%. Before the trials,

subjects were weighed (Tanita TBF-300, Tanita, Japan). Body weight (BW, kg) and total weight (TW, kg) (which comprised the sum of the weights of the subject, clothes, bike, SRM crankset, and K4 system) were recorded. The wind velocity was measured continuously with an anemometer (Alba, Silva, Sweden). The averaged 6-min and the maximal 5-s values were retained. The ambient temperature remained constant between 13° and 14°C throughout all trials. For all field trials, the subjects used their own bike fitted with a four strain gauges “professional” SRM crankset (SRM, Schoberer Rad Messtechnik, Fuchsend, Germany) and the same clothes. The bicycle tire pressure was inflated to 700 kPa. Each trial had a duration of 6 min and was preceded by a complete recovery of 10 min. During the first minute of each trial, the subjects were allowed to adjust the pedaling cadence and power output to the desired level. Thereafter, each subject was required to keep the power output constant at 75% of PPO in the five conditions by referring to the micro-bike computer termed “Powercontrol unit” fixed at the handlebar of the bicycle and to adjust the velocity for this purpose. The subjects were also required to keep the body position constant throughout the trial. In the seated position in the level ground and uphill trials, subjects were instructed to keep hands in “drops” and to keep constant the most aerodynamic body position. The use of an aerobar was not allowed. For the standing trials, subjects were instructed to keep the hands “on hoods.” The two level trials in a seated position were performed at sea level on a 450-m asphalt velodrome. The average and maximal wind velocities for the level trials were  $0.1 \pm 0.2$  and  $0.5 \pm 0.9$  m·s<sup>-1</sup>, respectively. The uphill trials were performed on a hill with an average gradient (5.3%) calculated as the ratio of the overall elevation (101 m) (Alba) to the distance (1900 m). The variability of four subsections (0–500 m, 500–1000 m, 1000–1500 m, and 1500–1900 m) gradients calculated by the same mean was small (CV = 2.1%). The bottom of the hill was at sea level. The average and maximal wind velocities for the uphill trials were  $1.1 \pm 0.8$  and  $2.2 \pm 1.5$  m·s<sup>-1</sup>, respectively.

**Anaerobic power tests.** Determination of the anaerobic power during the Wingate test was conducted in a separate day in three different conditions (1: Monark-Seated, 2: Max-Seated, 3: Max-Standing) in a randomized order with a complete recovery of 20 min (3). The Monark-Seated condition was a maximal sprint over 30 s begun from

TABLE 1. Individual characteristics of the subjects.

Subject	Age (yr)	Height (cm)	Body Weight (kg)	Overall Weight (kg)	PPO (W)	Training Characteristics		
						Training Duration (yr)	Training (km·yr <sup>-1</sup> )	Competition Level
1	24	179	69	80	460	12	30,000	Professional
2	27	178	74	88	430	10	20,000	Professional
3	19	167	68	77	370	12	10,000	National
4	18	188	71	85	400	5	18,000	National
5	18	181	74	88	340	4	14,000	Junior
6	17	171	60	76	340	4	13,000	Junior
7	22	177	60	76	340	4	12,000	Junior
8	24	177	60	74	370	6	12,000	National
Mean $\pm$ SD	20.7 $\pm$ 3.9	177.3 $\pm$ 6.3	67.0 $\pm$ 6.2	80.0 $\pm$ 6.2	381 $\pm$ 45	7.1 $\pm$ 3.6	16,125 $\pm$ 6,512	

Overall weight, sum of the weights of the subject, the clothes, the bicycle and the equipment (SRM, K4b<sup>2</sup>); PPO, peak power output.

rest and performed on a stationary cycle ergometer (Monark 818 E) that was instrumented with a strain gauge and an encoder to measure the friction force, the inertial force and the flywheel velocity, as described previously (1). Calculated instantaneous power was acquired at a sampling frequency of 50 Hz and averaged each 5 s for comparison with the other conditions. The second and third trials were maximal sprints over 30 s, respectively, in a seated or a standing position, performed by the subjects with their own bikes on a slightly ascending road. An assistant hold the bike for the start and the subject were in a seated position hands “on hoods.” The choice of the gear was free but identical in the two field-based conditions. Power output was averaged each 5 s by the SRM. In the three conditions, max power was defined as the highest averaged 5-s value, and mean anaerobic power as the averaged 30-s value. At the first and the third minute after completion of the test, 25- $\mu$ L capillary blood samples were taken from the fingertip and analyzed for lactate concentration by using the Lactate Pro (LT-1710, Arkray, Japan) portable analyzer. The maximal value was retained.

**Power output measurement.** The subjects’ bicycle crankset was changed for a SRM crankset calculating power output from the torque and the angular velocity of the cranks. With the “professional” SRM model used in the present study, four strain gauges are located between the crank axle and the chain-ring, and their deformation is proportional to the torque generated by each pedal revolution. Pedaling cadence and torque are inductively transmitted with a sampling frequency of 500 Hz to the Powercontrol unit. Data averaged every 5 s were displayed on the screen of the Powercontrol unit and recorded. Power output is calculated from torque and angular velocity continuously. Before each trial, the SRM crankset was calibrated according to the manufacturer’s recommended procedures. Briefly, a zero value was updated between each trial with the unloaded SRM (pedaling backward with the chain not mounted on the chain ring) because it can be modified slightly by changes in temperature and chain-ring bolt tension. The slope of the relationship between the frequency of the strain gauges and torque is calibrated during manufacture and therefore is unique for a given SRM. The reliability and accuracy of the “professional” SRM crankset has been reported by comparison with a motor-driven friction brake. It was reported an almost perfect relationship ( $R^2 = 0.99-1.0$ ) between the two systems (12,18,23). Moreover, the “professional” SRM was shown to have a very low ( $\pm 1.8\%$  or  $\pm 2$  W) variability (12). For all trials, the averaged 5-s data of velocity, pedaling cadence, and power output of the last 3 min of each trial were recorded and analyzed.

**Physiological data measurement.** During all field trials, a breath-by-breath portable gas analyzer (Cosmed K4b<sup>2</sup>, Rome, Italy), validated by McLaughlin et al. (19), and a chest belt (Polar Electro, Kempele, Finland) were used to collect metabolic and HR data. Calibration procedures were performed before each test according to the manufacturer’s instructions.  $\dot{V}O_2$ ,  $\dot{V}CO_2$ ,  $\dot{V}E$ , respiratory frequency (FR), respiratory exchange ratio (RER), and HR were continu-

ously recorded. At the end of each trial, subjects indicated their rating of perceived exertion (RPE) using the Borg 6–20 scale.

Gross external efficiency (GE, %) was calculated from measures of energy expended (EE, J·s<sup>-1</sup>),  $\dot{V}O_2$  (mL·kg<sup>-1</sup>·min<sup>-1</sup>) and power output (W) averaged over the last 3 min of each trial. As presented previously (21):

$$GE = \text{power output} \cdot 100\% / EE$$

$$\text{With } EE = [(3.869 \cdot \dot{V}O_2) + (1.195 \cdot \dot{V}CO_2)] \times [(4.186/60) \cdot 1000]$$

Economy (EC, kJ·L<sup>-1</sup>) was defined as the ratio of the power output by the oxygen consumption (21). In each condition, the slow component of  $\dot{V}O_2$  was defined as the difference between 1-min averaged values of end-exercise  $\dot{V}O_2$  and  $\dot{V}O_2$  measured at the third minute of exercise. In addition, the gross aerobic cost ( $C_{ae}$ , mL·kg<sup>-1</sup>·km<sup>-1</sup>) was calculated as the ratio of  $\dot{V}O_2$  by the velocity.

**Statistical analysis.** Mean and standard deviation were calculated for all variables. The overall CV of power output, GE and EC in the five trials were calculated as square root of the overall mean of the CVs squared. The normality of the distribution of the variables and the homogeneity of variance were tested and accepted (SigmaStat 2.0, Jandel Scientific, San Rafael, CA). Therefore, a repeated measures ANOVA (1 within, 0 between) complemented by a Scheffe’s *post hoc* test was used to identify differences in mechanical power output, velocity, pedaling cadence, heart rate,  $\dot{V}O_2$ ,  $\dot{V}E$ , RER, RPE, gross efficiency, and economy between the conditions at 75% of PPO and for differences between the three anaerobic power tests. For all statistical analyses, a *P*-value of 0.05 was accepted as the level of statistical significance.

## RESULTS

Table 2 shows the average power output generated by each subject in the uphill and level-ground trials. The required protocol-dependant power output corresponding to 75% of PPO was calculated as  $285.9 \pm 33.9$  W, and the overall mean of power output measured was  $284.9 \pm 34.6$  W with an overall CV of 4.1%. No differences were observed between the trials ( $P > 0.05$ ). Table 3 illustrates the individual GE results for each trial. The mean GE was  $22.4 \pm 1.5\%$  (CV = 5.6%). There were no significant differences between the five trials ( $P > 0.05$ ). The average results for economy in each trial are shown in Table 4. The overall mean EC was  $4.69 \pm 0.33$  kJ·L<sup>-1</sup> (CV = 5.7%) with no differences observed between the trials ( $P > 0.05$ ).  $C_{ae}$  was  $95.1 \pm 7.8$ ,  $185.5 \pm 12.8$ , and  $189.9 \pm 12.5$  mL O<sub>2</sub>·kg<sup>-1</sup>·km<sup>-1</sup> for Seated-Level, Seated-Uphill, and Standing-Uphill, respectively. The two uphill conditions were not significantly different but were greater ( $P < 0.001$ ) than the level condition. No differences ( $P > 0.05$ ) were observed in  $\dot{V}O_2$ , RER, or RPE, whereas pedaling cadence ( $P < 0.001$ ), velocity ( $P < 0.001$ ), HR ( $P < 0.001$ ), and  $\dot{V}E$  ( $P < 0.05$ ) were different between the trials. No slow component of  $\dot{V}O_2$  was observed in any condition.

TABLE 2. Power output of the five trials bysubject.

Subject	1	2	3	4	5	6	7	8	Mean
Level cycling									
Power1 (W)	327.3 ± 15.4	285.6 ± 37.5	277.9 ± 18.9	293.4 ± 30.1	255.3 ± 21.4	244.3 ± 19.8	215.0 ± 14.2	302.9 ± 31.0	275.2 ± 35.7
Power2 (W)	335.3 ± 15.4	321.5 ± 23.8	276.8 ± 15.7	308.0 ± 24.7	264.9 ± 19.1	235.1 ± 18.2	227.7 ± 20.5	303.2 ± 28.0	284.1 ± 39.6
Mean power (W)	331.3	303.5	277.4	300.7	260.1	239.7	221.4	303.1	279.6 ± 34.7
Uphill cycling									
<b>Seated position</b>									
Power1 (W)	337.8 ± 15.1	336.6 ± 17.3	272.2 ± 11.0	309.4 ± 16.6	271.1 ± 20.2	243.5 ± 11.9	246.1 ± 10.4	280.4 ± 19.5	287.1 ± 37.1
Power2 (W)	340.8 ± 8.5	336.2 ± 20.2	273.1 ± 10.3	311.6 ± 12.1	263.7 ± 17.7	242.0 ± 13.8	249.0 ± 10.3	271.9 ± 16.5	286.0 ± 38.5
Mean Power (W)	339.3 ± 11.8	336.4	272.7	310.5	267.4	242.8	247.5	276.2	286.6 ± 35.3
<b>Standing position</b>									
Power (W)	344.6 ± 13.1	331.6 ± 21.7	276.9 ± 12.6	312.4 ± 17.8	274.1 ± 18.7	254.5 ± 19.4	250.8 ± 13.3	292.2 ± 23.3	292.1 ± 34.6
CV (5 trials) (%)	1.9	6.6	0.9	2.5	2.7	2.9	6.6	4.8	4.1

No difference between trials was observed.

Table 5 shows the means, SD, and CV of power output, velocity, cadence, HR,  $\dot{V}O_2$ ,  $\dot{V}E$ , RER, RPE, GE, and EC in the three conditions (Seated-Level, Seated-Uphill, and Standing-Uphill). For the same given power output, velocity and cadence were significantly greater ( $P < 0.001$ ) in level ground than uphill cycling. Although  $\dot{V}O_2$ , RER, GE, and EC were not different between the three conditions, HR was significantly ( $P < 0.05$ ) higher in the standing position.  $\dot{V}E$  was higher ( $P < 0.05$ ) when cycling uphill in the standing than in the seated position. FR was significantly ( $P < 0.05$ ) lower in Seated-Uphill ( $33.6 \pm 3.2$  cycles·min<sup>-1</sup>) than in Seated-Level ( $36.6 \pm 5.8$  cycles·min<sup>-1</sup>) or in Standing-Uphill ( $37.0 \pm 3.3$  cycles·min<sup>-1</sup>).

Max power in Max-Standing 30-s sprint ( $935 \pm 88$  W) was significantly greater ( $P < 0.01$ ) than in Monark-Seated ( $762 \pm 85$  W) and in Max-Seated ( $784 \pm 98$  W) Wingate tests. Moreover, because there were no differences in the end-exercise blood lactate concentration between the three trials ( $16.2 \pm 3.5$ ,  $16.4 \pm 3.6$ , and  $17.0 \pm 3.6$  mmol·L<sup>-1</sup> for Monark-Seated, Max-Seated, and Max-Standing, respectively), the mean power measured over 30 s was higher ( $P < 0.01$ ) in the standing than in the two seated (laboratory and field) conditions (Fig. 1). The maximum and mean pedaling cadences were higher ( $P < 0.01$ ) in Monark-Seated ( $131.0 \pm 23.1$  and  $114.9 \pm 18.5$  rpm) than in Max-Seated ( $107.8 \pm 6.6$  and  $98.3 \pm 7.4$  rpm) or Max-Standing ( $104.2 \pm 13.5$  and  $93.4 \pm 11.1$  rpm). No differ-

ence in pedaling cadence was observed between the two field-based conditions.

## DISCUSSION

The main findings of the present study are that level-seated, uphill-seated, or standing-cycling positions exhibit similar external efficiency and economy in trained cyclists at a submaximal intensity. In contrast, HR is higher in a standing as opposed to a seated position. In addition, during a maximal 30-s sprint, the power output is ~25–30% greater in a standing position than when seated.

It has been reported that differences in  $\dot{V}O_2$  and economy,  $\dot{V}E$ , and HR between the seated and the standing positions are influenced by the intensity of exercise, the gradient, the pedaling cadence, and the technical expertise of the subject.

**Intensity.** The present results conflict with those of Tanaka et al. (29) and Ryschon and Stray-Gundersen (24), who reported in treadmill cycling an increase in  $\dot{V}O_2$  of ~6% and ~12%, respectively, between the uphill-seated and standing positions at low intensities, ~50% and ~60% of  $\dot{V}O_{2max}$ , respectively. It is assumed that at moderate-exercise intensities the extra work of the upper body muscles in the standing position accounts for a greater proportion of the overall mechanical work produced and therefore leads to a significant increase in  $\dot{V}O_2$  when compared with cycling in a seated position. At higher exercise intensities (>70% of

TABLE 3. Gross efficiency results of the five trials bysubject.

Subject	1	2	3	4	5	6	7	8	Mean
Level cycling									
GE1 (%)	22.0	21.4	21.3	20.6	23.6	21.0	20.4	22.8	21.6 ± 1.1
GE2 (%)	23.4	24.4	22.4	21.3	24.0	22.7	25.3	22.6	23.3 ± 1.3
Mean GE (%)	22.7	22.9	21.8	21.0	23.8	21.8	22.8	22.7	22.4 ± 0.8
Uphill cycling									
<b>Seated position</b>									
GE1 (%)	22.0	22.4	22.6	21.5	21.4	20.8	20.6	24.1	21.9 ± 1.1
GE2 (%)	22.7	23.1	23.1	22.4	22.0	20.9	19.8	25.2	22.4 ± 1.6
Mean GE (%)	22.3	22.8	22.8	21.9	21.7	20.9	20.2	24.7	22.2 ± 1.3
<b>Standing position</b>									
GE (%)	22.4	22.6	23.6	21.7	20.9	20.7	21.7	26.5	22.5 ± 1.9
CV (5 trials) (%)	2.5	4.9	3.8	3.0	6.2	3.8	10.1	6.8	5.6

No difference between trials was observed.



TABLE 4. Economy results of the five trials bysubject.

Subject	1	2	3	4	5	6	7	8	Mean
Level cycling									
EC1 (kJ·L <sup>-1</sup> )	4.6	4.5	4.4	4.3	4.9	4.4	4.3	4.9	4.5 ± 0.2
EC2 (kJ·L <sup>-1</sup> )	4.9	5.2	4.7	4.5	5.1	4.8	5.3	4.8	4.9 ± 0.3
Mean EC (kJ·L <sup>-1</sup> )	4.7	4.8	4.6	4.4	5.0	4.6	4.8	4.7 ± 0.2	
Uphill cycling									
<b>Seated position</b>									
EC1 (kJ·L <sup>-1</sup> )	4.6	4.6	4.8	4.5	4.6	4.4	4.2	5.1	4.6 ± 0.3
EC2 (kJ·L <sup>-1</sup> )	4.8	4.8	4.8	4.7	4.6	4.4	4.2	5.3	4.7 ± 0.3
Mean EC (kJ·L <sup>-1</sup> )	4.7	4.7	4.8	4.6	4.4	4.2	5.2	4.6 ± 0.3	
<b>Standing position</b>									
EC (kJ·L <sup>-1</sup> )	4.6	4.7	4.9	4.6	4.5	4.3	4.6	5.8	4.7 ± 0.5
CV (5 trials) (%)	2.7	5.4	3.9	2.7	5.6	3.9	10.0	7.5	5.7

No difference between trials was observed.

$\dot{V}O_{2max}$ ), forces applied to the handlebar with the upper limbs in the seated situation are increased two- to three-fold (26), explaining partly why the differences in  $\dot{V}O_2$  between the uphill standing and seated situations disappear. The present results showing no change in oxygen consumption between the seated and the standing positions are in line with those of Swain and Wilcox (28) and Miller et al. (20), which were conducted with experienced cyclists on treadmill cycling at similar intensities (~75% of  $\dot{V}O_{2max}$ ). Moreover, Tanaka et al. (29) reported also that at a higher intensity (~83%, of  $\dot{V}O_{2max}$ ), standing and seated positions induced the same  $\dot{V}O_2$  response. The present results are also supported by those of Koga et al. (15) reporting that supine cycling lead to the same steady-state  $\dot{V}O_2$  in moderate-intensity exercise and to the same end-exercise  $\dot{V}O_2$  during heavy exercise relative to upright cycling. HR was lower in the supine position and the  $\dot{V}O_2$  kinetics were slower, which could be partly caused by the reduced HR. The reduction in arterial pressure in the legs occurring in the supine position is countered by an improved venous return, facilitated by the muscle contractions in cycling (15) and by a redistribution of blood flow (11).

**Gradient.** In the present study, no difference in  $\dot{V}O_2$  was shown between the two seated situations at the same given power output when cycling on level ground or ascending a hill. Therefore, the gradient does not appear to be a factor that influences cycling efficiency at the same mechanical power. However, it is likely that the use of a standing position for a given power output would become more beneficial as the gradient of the climb become steeper, mainly because of the smaller cadences observed in steep climbs (17,28). Thus, greater forces per revolution generated by the lower limbs while standing would be required

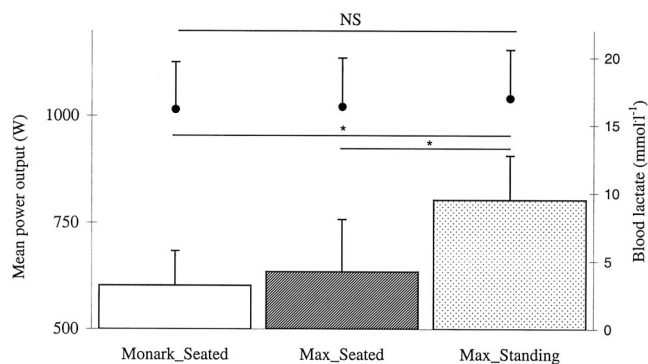
(16). When taking into account the aerodynamic drag, the benefits of using the standing position as gradient increases seems even more logical, because the negative influence of the higher aerodynamic drag due to the standing position is reduced as the velocity declines. The contribution of the aerodynamic drag ( $R_a$ ), the rolling resistance ( $R_r$ ), and the drag to overcome the gravity when climbing ( $R_g$ ) to the total resistance opposing to the motion of a subject ( $R_T$ ) is mainly influenced by the velocity and the gradient. In the present study,  $R_a$ ,  $R_r$ , and  $R_g$  were approximated with the following parameters: mechanical power output = 280 W,  $\rho$  (air density) = 1.22 kg·m<sup>-3</sup>,  $AC_d$  (effective frontal area in seated position) = 0.302 m<sup>2</sup>,  $Cr$  (coefficient of rolling resistance) = 0.01,  $M$  (overall weight) = 80.0 kg, and  $\sin(\alpha)$  (gradient) = 0.053. In the Seated-Level condition at the velocity of 35.8 km·h<sup>-1</sup>,  $R_T$  was 28.3 N with  $R_a$  contributing to ~80% of  $R_T$ . In the Seated-Uphill condition at a velocity of 18.3 km·h<sup>-1</sup>,  $R_T$  was doubled (56.8 N) with  $R_a$  and  $R_g$  representing ~8% and ~82% of  $R_T$ , respectively. Therefore, when ascending a hill of a moderate gradient, the increase in  $AC_d$  related to the standing position would have only a very limited influence on the total resistance when climbing. This is highlighted by  $C_{ae}$ , calculated by taking into account the velocity, which was not different between these two positions although significantly lower in level cycling.

**Cadence.** In the present study, the pedaling cadence was ~60 rpm in the two uphill conditions and ~90 rpm in level cycling. These results are close to those of Lucia et al. (17) reporting that professional cyclists exhibited cadences of 70 and 89 rpm in uphill climbing and flat time-trial, respectively, where the intensity, as measured during competitions, was greater than in the present study. The influ-

TABLE 5. Values of mechanical power output ( $P_{mec}$ ), velocity ( $V$ ), pedaling cadence (cadence), heart rate (HR), oxygen consumption ( $\dot{V}O_2$ ), ventilation ( $E$ ), respiratory exchange ratio (RER), rate of perceived exertion (RPE), gross efficiency (GE), and economy (EC) in level and uphill-seated and standing positions; mean ± SD (CV).

Condition	$P_{mec}$ (W)	$V$ (km·h <sup>-1</sup> )	Cadence (rpm)	HR (bpm)	$O_2$ (mL·kg <sup>-1</sup> ·min <sup>-1</sup> )	$E$ (L·min <sup>-1</sup> )	RER	RPE (points)	GE (%)	EC (kJ·L <sup>-1</sup> )
Seated-Level	279.6 ± 34.7 (3.8%)	35.8 ± 1.7 (1.4%)	90.5 ± 6.5 (1.4%)	160.3 ± 8.9 (1.9%)	53.3 ± 1.8 (5.1%)	94.8 ± 16.1 (3.2%)	0.97 ± 0.03 (2.2%)	10.0 ± 1.6 (7.1%)	22.4 ± 0.8 (6.9%)	4.7 ± 0.2 (7.0%)
Seated-Uphill	286.6 ± 35.3 (1.1%)	18.3** ± 1.3 (1.0%)	58.9** ± 4.1 (1.1%)	161.4 ± 9.3 (2.1%)	55.3 ± 1.2 (2.5%)	88.5 ± 10.9 (5.2%)	0.95 ± 0.03 (3.6%)	11.1 ± 2.3 (4.1%)	22.2 ± 1.3 (2.3%)	4.6 ± 0.3 (1.9%)
Standing-Uphill	292.1 ± 34.6	17.9** ± 1.2	58.5** ± 4.1	169.9*# ± 12.1	55.4 ± 5.3	97.2# ± 8.1	0.97 ± 0.05	9.9 ± 1.9	22.5 ± 1.9	4.7 ± 0.5

\*  $P < 0.05$ , \*\*  $P < 0.001$  for differences with the Seated-Level condition; #  $P < 0.05$  for differences between the Seated-Uphill and the Standing-Uphill conditions.



**FIGURE 1**—Mean power output (bar) and end-exercise lactate concentration (●) in a 30-s cycling sprint in three conditions: seated position on an ergometer Monark (Monark-Seated), seated position in field-based cycling (Max-Seated), and standing position in field-based cycling (Max-Standing). \*  $P < 0.01$  for differences in power output. No differences were observed in lactate concentration between the three conditions.

ence of the cadence in uphill cycling was studied by Swain and Wilcox (28), who reported that a cadence of 81 rpm was more economical than a cadence of 41 rpm in a seated treadmill cycling with a gradient of 10%. In contrast, Tanaka et al. (29) reported that  $\dot{V}O_2$  was not changed by an increase from 48 to 60 rpm in treadmill cycling. In these previous studies conducted on a motorized treadmill (28,29), the cadence was imposed, which could have influenced the metabolic responses of the subjects (14). In the present study, subjects were free to choose the most preferred gear and pedaling cadence, and to the best of our knowledge, it is the first study to show that the cadence is the same in well-trained cyclists between seated and standing positions when climbing at a given power output. The present results suggest that at 75% of PPO, pedaling cadence has a negligible effect on energy consumption and economy during uphill or level ground cycling.

**Technical expertise.** The technical features of the standing position may be one of the most determining factors affecting the metabolic responses. The tilting motion of the bike side to side (26) and the relaxation of the upper body muscles could modify greatly the energy expenditure when “out of the saddle.” These factors are difficult to examine in a field-based study. However, if using the anthropometrical characteristics described in Padilla et al. (22), the cyclists of the present study would have been classified as “uphill” or “all-terrain” specialists, because they exhibit a relatively low body mass of  $67.0 \pm 6.2$  kg that would give them advantages in uphill but relatively high  $BSA \cdot BM^{-1} \cdot 10^{-3}$  (body surface area per unit of body mass) and  $FA \cdot BM^{-1} \cdot 10^{-3}$  (frontal area per unit of body mass) of  $27.5 \pm 1.5$  and  $5.1 \pm 0.3$ , respectively, indicating a high aerodynamic resistance per unit of body mass that is disadvantageous when time-trialing. In a more anecdotal way, subject 1 was a world-class “climber.” One cannot rule out that the technical characteristics and the high expertise level of the present subjects had an influence in minimizing the energy expenditure when climbing in a standing position. Specialists of time-trial or flat-road races exhibit a higher

energy expenditure when climbing in a standing position and therefore probably a greater difference between seated and standing positions (22). Further studies are therefore needed to investigate the effect of the technical and anthropometrical characteristics of the subjects on the different positions’ efficiency.

**Ventilation.** In uphill cycling, the standing position was characterized by a greater ventilation response than the seated position. In maximal exercise,  $\dot{V}E$  is greater in upright than in supine position ( $157$  vs  $131$  L·min<sup>-1</sup>) (11), whereas in submaximal exercise, no differences are generally reported. For example, Koga et al. (15) found no differences between upright and supine position in moderate or heavy cycling exercise. Two reasons could explain why there were no significant differences in  $\dot{V}E$  between the two seated positions. First, although the cost of the internal work gets higher as pedaling cadence increases, the direct effect of cadence on the breathing pattern for a given work rate has not been clearly identified (13). However, in the present study, the respiratory frequency was greater in the level than in the uphill seated position. Second, one could assume that, when cycling on the velodrome, the athletes maintain a position more aerodynamic than when climbing seated and therefore for the same power output and with the same hands’ position on the handlebar, the trunk angle was slightly modified as result of the gradient change. It was shown previously that a greater trunk flexion can result in an elevation of the respiration without any metabolic demand differences, mainly because of an abdominal compression hampering the work of the diaphragm (9).

**Heart rate.** It is well documented that heart rate is influenced by the body position. When changing from the supine to the upright position, blood venous return, and then cardiac output, is reduced, leading to a decrease in arterial pressure and, through the baroreceptors feedback, to a reduction of the parasympathetic activity and an increase in the adrenergic stimuli, which cause a rise in HR. Hughson et al. (11) reported a significantly higher HR in upright than in supine position in maximal cycling exercise ( $197$  vs  $185$  bpm) but no differences between the two positions in moderate exercise. Koga et al. (15) showed that in moderate exercise, the supine position was associated to a lower HR than in upright position, whereas the differences were reduced in heavy exercise. The existing data examining the difference in HR between standing and seated cycling are inconsistent (20,28,29), mainly affected by the exercise intensity. Tanaka et al. (29) and Ryschon and Stray-Gundersen (24) reported a HR increase of 4–6% and 8% from the seated to the standing position at low intensities, whereas Swain and Wilcox (28) found no differences between seated and standing positions at an intensity close to the one of the present study. However, because Kenny et al. (14) highlighted that the  $\dot{V}O_2$ -HR relationship is modified by the laboratory environment, comparison with the present field-based study may not be relevant.

**Efficiency.** In the present study, GE was not affected by gradient (ground-level vs uphill conditions) or body position. However, a new finding of this study was that in

well-trained cyclists, there are no differences in efficiency between standing and seated positions. The present average value of GE ( $22.4 \pm 1.5\%$ ) is in line with the previous results measured in well-trained cyclists; i.e., 21.9% (10) or 22.6% (23), but higher than values measured in less-trained cyclists or in fatigued state. The coefficient of variation of 5.6% was slightly above the value of 4.2% previously reported in ergometer cycling (21) but lower than values associated to delta efficiency ( $CV > 6\%$ ). We conclude that the measurement of field-based gross efficiency is a valid method for tracking the variation of fitness in trained cyclists.

The main difference between the two seated conditions is the higher pedaling cadence in the ground-level compared to the uphill trials (90 vs 59 rpm). In the present study, one could have expected a higher efficiency in Seated-Uphill than in Seated-level condition, due to the difference of cadence that is related to the cost of unloaded cycling increasing as cadence increases. In a previous study (8) with unskilled subjects, GE decreased as cadence increased, whereas Sidossis et al. (25) reported that in well-trained cyclists at an intensity (80% of  $\dot{V}O_{2max}$ ) similar to the present one, there were no differences in GE between cadences of 60, 80, or 100 rpm. Therefore, it is possible that long-term training results in the ability to use a higher pedaling cadence without changing the metabolic cost of the work performed. Upper-body isometric contractions contribute significantly to the production of power output in cycling because the electromyographic activity of the forearm muscles is influenced by the hand grip on the handlebar (2). It is hypothesized that there is an increase in the activity of the muscles of the arms and/or trunk as intensity increases (4). Skilled cyclists have an energetically optimal (i.e., eliciting the smallest energy consumption) pedaling cadence higher than the unskilled cyclists and are thought to enhance less the isometric contractions of the upper-body muscles when climbing seated. However, the influence of pedaling cadence, exercise intensity, or ability level on the activity of the trunk/arms/forearms/hands muscles and their contribution to the production of external mechanical power are still unsolved. One could hypothesize that upper-body isometric contractions influence to a large extent the efficiency in field-based cycling.

**Maximal anaerobic test.** In the present study, complementary to GE and EC comparison between the three conditions, measurement of the maximal anaerobic power was carried out by comparison with a referenced method, the Wingate test on a Monark ergometer (3). One could argue that maximum and mean power output could have been affected by the difference in crank length because it was shown that different crank lengths would result in different upright power output production in a Wingate test; i.e., 945 W and 968 W with crank lengths of 145 mm and 180 mm, respectively (30). In the present study, the crank lengths of the Monark was 175 mm, and the crank lengths of the bikes used in the field trials were 175 or 177.5 mm. Therefore, one could assume that the bias due to the crank

length difference was negligible. The Wingate test has been shown to be a good predictor of uphill-cycling performance (6). On a hill with a similar gradient (6%) than in the present study, performance over 16 min at 330 W was highly related to the average power produced during the Wingate test divided by body mass (6). In the standing position, maximum and mean power generated during the Wingate test were significantly higher by ~20% and ~30%, respectively, than in the two seated positions, with the end-exercise blood-lactate concentration being the same in the three conditions. These results show that a greater short-term power can be produced in the standing versus seated position, presumably due to a greater force developed per revolution. In the present study, because the pedaling cadence was significantly greater with the Monark than in the two field-based tests, one could argue that the resistance (friction force) was not the same between the ergometer and the two-field conditions and that could have affected the power produced. However, all athletes sustained a maximal effort as shown by the same elevated blood lactate concentration in the three tests; second, because there were no differences in cadence between Max-Seated and Max-Standing, the difference in mechanical power was explained mainly by the greater force in the standing condition. Li and Caldwell (16) showed that the rectus femoris and the gluteus maximus exhibited a greater EMG activity (mean or iEMG) in the standing position. Moreover, the gluteus maximus, the tibialis anterior, and the vastus lateralis had an EMG activity over a longer part of the crank cycle. These muscles are hip and knee extensors and are highly involved in the development of forces in cycling.

**Conclusions.** In well-trained cyclists, economy and gross-external efficiency in seated cycling were not different than in uphill standing cycling, suggesting therefore that the choice of the position is not obvious, as confirmed by observations of competitive cyclists. Moreover, the standing position elicited higher heart rate and ventilation responses for the same work rate, and, in maximal 30-s sprints, the mechanical power was higher with the standing position than with the seated ones. These results suggest indirectly that cyclists would prefer the standing position during short climbs at very high intensity (i.e., due to the gradient) and the seated position in long “steady-state” climbs. However, because a single gradient was used, the present study was not designed for predicting which combination of speed and hill gradient would favor climbing in the standing position. Further studies are also required for investigating whether the technical and anthropometrical characteristics of the subjects would influence to a great extent their efficiency and economy in standing cycling.

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Address for correspondence: Millet Grégoire, Faculté des Sciences du Sport, Université de Montpellier 1, 700 Av. Pic Saint Loup, 34090 Montpellier, France; E-mail: g.millet@staps.univ-montp1.fr.



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