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Effect of Cycling Position on Ventilatory and Metabolic Variables

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Three positions are generally used by cyclists: upright posture (UP), dropped posture (DP) and aero posture (AP). They determine different angles of trunk flexion which could be associated with physiological changes. The purpose of this study was to analyse the effect of these rider positions on ventilatory and metabolic variables. Nine male competitive cyclists (26.3 ± 3 yrs, mean ± SD) exercised on a cycle ergometer. Subjects performed three 10 min exercise bouts at 70% $\dot{V}O_2max$ (maximal oxygen uptake, $l \cdot min^{-1}$) in UP, DP and AP, in a randomized order. Each bout was separated by a 5 min active recovery period (50% of $\dot{V}O_2max$). Ventilatory and gas exchange responses to exercise were averaged every min. Blood lactate concentration ($[La]_b$, mM), blood pH were analysed at the 5th and the 10th min. The ventilation, respiratory exchange ratio, mean inspiratory flow, $[La]_b$ and perceived exertion were significantly higher in DP (88.4 ± 11.4 $l \cdot min^{-1}$, 0.96 ± 0.05 $ml \cdot s^{-1}$, 2.52 ± 0.84 Mm and 13.6 ± 1.2) than in UP (84.8 ± 12.3 $l \cdot min^{-1}$, 0.94 ± 0.05 $ml \cdot s^{-1}$, 2.14 ± 0.99 Mm and 12.1 ± 1.5). $\dot{V}O_2$, tidal volume, carbon dioxide output, respiratory rate, inspiratory duty cycle, heart rate and pH remained unchanged between all riding positions (averaged values for the three positions: 3.09 ± 0.006 $l \cdot min^{-1}$, 2.34 ± 0.006 $l \cdot br^{-1}$, 3.01 ± 0.04 $l \cdot min^{-1}$, 37.4 ± 0.8 $br \cdot min^{-1}$, 0.47 ± 0, 162 ± 1 $beat \cdot min^{-1}$ and 7.38 ± 0.015). These results showed that the greater changes in ventilatory and metabolic variables occurred in DP. AP appears to be the more suitable position when the aerodynamic drag becomes predominant.

Key words: Cycling, body position, ventilation, perceived exertion, oxygen uptake, blood lactate concentration.

Introduction

Three riding positions are generally used by cyclists according to the type of race and the profile of the terrain. Upright posture (UP) is mainly used when pulling up on the handlebars to ride in hill terrain. Dropped posture (DP) is adopted at high speeds to reduce the projected frontal area in order to minimize the aerodynamic drag and energy expenditure (26). Aero posture (AP) is generally used during individual time trials and has the lowest aerodynamic drag of these three riding positions. The projected frontal area is lower for DP and AP than UP as the result of the trunk flexion and optimal position of the upper limbs (15, 25). The aerodynamic saving determined by the trunk flexion is well established (10, 15, 16, 17, 18). Nevertheless, there is still controversy about the effect of trunk flexion on the ventilatory and metabolic responses. Several previous studies have failed to demonstrate a significant effect of cycling position on ventilatory and metabolic responses during exercise performed on an cycle ergometer for submaximal work rates (2, 14) (UP vs DP; DP vs AP) and for maximal work rates (23, 31) (UP vs AP; UP vs DP). In laboratory, body posture (UP vs DP) also did not affect metabolic responses during uphill bicycling at submaximal work rates (27). Moreover, Franke et al. (9) using continuous wave Doppler echocardiography have shown that the riding position (UP vs DP vs AP) did not affect the physiological response to maximal cycle ergometer exercise. Conversely, Faria et al. (7) have reported significant differences in ventilatory and metabolic responses. These authors have observed a higher ventilation ($\dot{V}_E$, $l \cdot min^{-1}$) at maximal exercise and a higher oxygen uptake ($\dot{V}O_2$, $l \cdot min^{-1}$) at submaximal exercise for DP than for UP.

The purpose of this study was to investigate the effect of the riding position (UP, DP, AP) on ventilatory and metabolic responses during submaximal cycling exercise. Since previous studies (7, 9, 23, 31) failed to find any difference in $\dot{V}O_2max$ between the different positions, the work rate was fixed at 70% of the $\dot{V}O_2max$ in UP in the three positions.

Methods

Subjects

Nine male competitive cyclists (national level), accustomed to ergometer exercises, participated in this investigation after they were informed of their rights as subjects, possible risks

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of the study, and signed an informed consent. Their mean (± SD), age, mass, height and $\dot{V}O_2max$ were 26.3 ± 3.0 yrs, 67.3 ± 3.2 kg, 1.76 ± 0.06 m and 66.3 ± 4.3 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. No participant had a history of cardiopulmonary disease, all were non-smokers, and none of them was taking alcohol or medication. The experimental protocol had been previously reviewed and approved by an Ethics Committee (Région de Franche-Comté, France) for the protection of human subjects.

Protocol

This study was conducted in a laboratory on a cycle ergometer to eliminate the aerodynamic drag and thus to isolate the effects of body position on physiological variables. Subjects visited the laboratory on two separate occasions. During the first visit, subjects completed an incremental exercise test for the determination of $\dot{V}O_2max$. $\dot{V}O_2max$ was used to establish the exercise intensity (70% of $\dot{V}O_2max$) during the second visit. Subjects exercised on a mechanical-braked Monark cycle ergometer (model 818 E). The cycle ergometer was modified by the addition of standard drop-style handlebars, a specially designed seat tube and road racing pedals with toe clips and straps. A racing saddle was fixed on a special saddle-tube which allowed forward and backward adjustments. The handlebars were fixed on a racing stem which allowed height adjustments. The ergometer was calibrated before each test according to the recommendations of the manufacturers. The exercise protocol consisted of a 5 min warm-up at 50% of $\dot{V}O_2max$. After this period, the work rate was incremented by 35 W every 3 min until exhaustion. The two criteria for achievement of $\dot{V}O_2max$ were both the failure of the subject to continue despite intense encouragement and the incapacity to maintain a pedalling frequency of 70 rpm.

During the second visit, subjects completed three continuous exercise bouts in three different positions (UP, DP and AP). After the warm-up (50% of $\dot{V}O_2max$), subjects cycled for 10 min in each of the three positions. Between each 10 min bout, a recovery period of 5 min at 50% of their $\dot{V}O_2max$ took place. The subjects maintained a pedalling frequency of 70 rpm by monitoring the screen of the cycle ergometer. The order of the riding positions was randomized. Before the beginning of the first exercise bout, their individual saddle heights and stem heights were determined according to the heights of the personal road bicycles.

They were kept constant throughout the study. During exercise (i.e. when the measurements were performed), UP was characterized by subjects placing their hands on the brake lever hoods. During the recovery period (i.e. when no measurement was performed), subjects placed their hands on the top of the standard racing handlebars. In DP, subjects had their hands on the lower part (on the bottom) of the handlebars. In both UP and DP, subjects were required to maintain elbow extension throughout the test. In AP, aero-handlebars (Mavic, France) were fixed on the standard drop-style handlebars. Subjects placed their elbows on the pads of aero-handlebars with their forearms directed in front of them, the hands grasping the top of the handlebars. Aero-handlebars were adjusted to obtain an arm-forearm angle close to 90 degrees, with 10 degrees tolerance (aero-handlebars allowed forward and backward adjustments). Subjects maintained a head-up position throughout the exercise. Verbal feedback was given to the subjects to ensure that they maintained a constant riding position during each part of the test. During the test, subjects were cooled by a fan placed in front of them.

Physiological measures

During the test, $\dot{V}O_2$, $\dot{V}_E$, carbon dioxide output ($\dot{V}CO_2$, $l \cdot min^{-1}$), tidal volume (V_T, l), respiratory rate (R_R, $br \cdot min^{-1}$) were measured continuously with a Cardiopulmonary Exercise System CPX/D (Medical Graphics, MSE, Strasbourg). The system's gas analyzers were calibrated prior to testing with gases of known concentrations. All ventilatory variables were averaged every min. The subject was connected to a facial mask with inhalation/exhalation valve diaphragms (150 ml dead space). Mean inspiratory flow (V_T/T_I, $ml \cdot s^{-1}$), inspiratory duty cycle (T_I/T_{Tot}) and respiratory exchange ratio (RER) were calculated. Heart rate (H_R, $beat \cdot min^{-1}$) was recorded and averaged every min with a Polar Sport Tester (model PE 3000). Ventilatory variables and H_R were analysed from the 3rd to the 10th min of the exercise bouts in order to eliminate the fast increase in these variables at the onset of the exercise. Arterialized capillary blood samples were taken at the tip of the subject's finger at the 5th min and the 10th min during the exercise period. Blood samples were analysed to determine 1) lactate concentration ($[La]_b$, mM), using the method of Noll (1978) (Boehringer Mannheim, Meylan) and 2) pH, using an electrochemical method (Corning 178 device, Strasbourg).

Rating of perceived exertion

Prior to the cycle ergometer test standardized directions for RPE were read to each subject. They were instructed to give an overall rating of perceived exertion using Borg's 6–20 point scale (3). Perceptual scale anchors were established as reported previously (3). These ratings represented an integration of each exercise bout sensation (in each position) and was recorded at the beginning of the 5 min active recovery period.

Statistical analysis

Differences in ventilatory and metabolic variables between the three riding positions were analysed by using a two-way analysis of variance (ANOVA), i.e. riding position (UP, DP and AP) and time (3rd to 10th min or 5th and 10th min according the variables). A one-way ANOVA was performed to analyse differences in RPE between the riding positions. When the effect of the riding position factor was significant, the Fisher's PLSD test was conducted to assess the differences between the three positions. Correlations were analysed by using linear regression. A p value < 0.05 was considered significant.

Results

The differences in the variables with respect to the time of exercise were not significant. The ventilatory and metabolic variables are given in Table **1** for each riding position. DP yielded a significantly higher $\dot{V}_E$ ($p < 0.01$), V_T/T_I ($p < 0.01$), $[La]_b$ ($p < 0.05$) and RER ($p < 0.01$) than UP. This was associated with a significantly higher RPE ($p < 0.05$) for DP when compared to UP. AP yielded also a significantly higher RER ($p < 0.05$) and $[La]_b$ ($p < 0.05$) when compared to UP. In order to illustrate these results, the mean differences between UP and both DP and AP were computed for $\dot{V}_E$, V_T/T_I, RER $[La]_b$ and RPE. The mean changes normalized with respect to UP value (Δ) in $\dot{V}_E$, V_T/T_I and RPE for DP, were 5.7 ±4.1%, 4.8 ± 3.5% and 15.9 ± 8.6%, respectively (Fig. **1**). The mean changes were 2.8 ± 2.4% and 2.0 ± 0.7% for RER and 25.5 ± 25.9% and 29.7 ± 27.2% for $[La]_b$ at DP and AP, respectively (Fig. **2**). Additionally, $\dot{V}O_2$, $\dot{V}CO_2$, V_T, R_R, T_I/T_{Tot}, pH and H_R remained unchanged between the three riding positions (Table **1**). When comparing UP with DP significant correlations were found between $\Delta\dot{V}_E$ and ΔR_R ($r = 0.96$, $p < 0.001$) and between $\Delta\dot{V}_E$ and ΔV_T ($r = -0.72$, $p < 0.05$). Fig. **3** exhibited representative on-line records for $\dot{V}O_2$, $\dot{V}_E$ and R_R related to time (from the 3rd to the 10th min of the exercise bouts) for each of the positions from three different subjects.

Table 1 Ventilatory and metabolic responses and rating of perceived exertion (RPE) for the three riding positions.

Variable	Upright posture	Dropped posture	Aero posture
$\dot{V}O_2$ (ml · min⁻¹ · kg⁻¹) STPD	45.8 ± 4.1	46.0 ± 4.1	46.0 ± 3.7
$\dot{V}O_2$ (l · min⁻¹) STPD	3.08 ± 0.37	3.09 ± 0.37	3.09 ± 0.33
$\dot{V}CO_2$ (l · min⁻¹) STPD	2.96 ± 0.30	3.04 ± 0.30	3.02 ± 0.28
$\dot{V}_E$ (l · min⁻¹) BTPS	84.8 ± 12.3	88.4 ± 11.4**	85.9 ± 11.9
RER	0.94 ± 0.05	0.96 ± 0.05**	0.95 ± 0.06*
R_R (br · min⁻¹)	36.9 ± 7.1	38.4 ± 6.4	37.0 ± 6.1
V_T (l) BTPS	2.33 ± 0.32	2.34 ± 0.31	2.34 ± 0.26
T_I/T_{Tot}	0.47 ± 0.01	0.47 ± 0.01**	0.47 ± 0.01
V_T/T_I (ml · s⁻¹)	3.11 ± 0.40	3.23 ± 0.37**	3.15 ± 0.39
H_R (beats · min⁻¹)	161 ± 11	163 ± 10	162 ± 10
$[La]_b$ (Mm)	2.14 ± 0.99	2.52 ± 0.84*	2.54 ± 1.26*
pH	7.38 ± 0.06	7.40 ± 0.03	7.37 ± 0.05
RPE	12.1 ± 1.5	13.6 ± 1.2*	12.8 ± 1.9

All values are means (± SD). $\dot{V}O_2$: oxygen uptake; $\dot{V}CO_2$: carbon dioxide output; $\dot{V}_E$: ventilation; V_T: tidal volume; R_R: respiratory rate; RER: respiratory exchange ratio; V_T/T_I: mean inspiratory flow; T_I/T_{Tot}: inspiratory duty cycle; H_R: heart rate; $[La]_b$: arterialized blood lactate concentration.
* significant different from UP at $p < 0.05$.
** significant different from UP at $p < 0.01$.

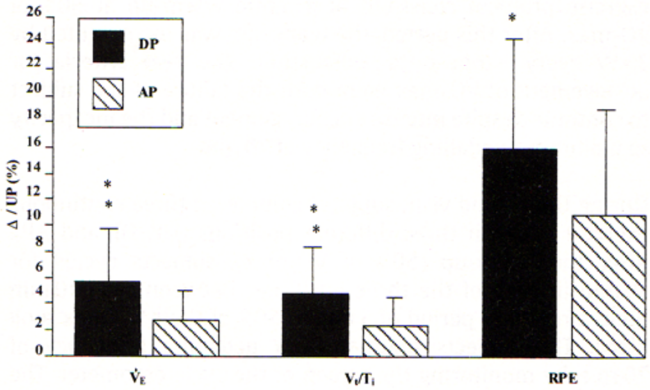

Fig. 1 Mean changes (Δ) normalized with respect to upright position (UP) in ventilation ($\dot{V}_E$, l · min⁻¹), mean inspiratory flow (V_T/T_I, ml · s⁻¹) and rating of perceived exertion (RPE) for dropped position (DP) and aero position (AP). *: significant difference from UP at $p < 0.05$, and **: significant difference from UP at $p < 0.01$. (Statistical analysis performed on the non-transformed data).

Discussion

The major findings of the present study were: 1) the higher RPE and ventilatory response to submaximal exercise for DP than UP and 2) the lack of significant difference in ventilatory and metabolic responses between DP and AP.

The present findings are in conflict with the data of the literature. Previous studies generally failed to find any differences in ventilatory and metabolic responses to exercise 1) during short-term incremental exercise bouts until volitional exhaustion between UP, DP and AP (9) and between UP and AP (23); 2) during a one hour exercise at 80% of $\dot{V}O_2$max between UP and AP (2); and 3) during ten minutes at 80% of $\dot{V}O_2$max between DP and AP (14). To the best of our knowledge, only Faria et al. (7) observed for exercise at 84% of $\dot{V}O_2$max in DP a 10% increase in $\dot{V}O_2$ and a 8.3% increase in $\dot{V}_E$ when compared to UP. Conversely, in the present study, the difference in $\dot{V}_E$ between DP and UP was not associated to a difference in $\dot{V}O_2$. The discrepancies between the present and previous results could arise from the small differences observed in metabolic and ventilatory variables between the riding positions. These differences were generally within the measurement precision and could explain the lack of statistically significant results in previous studies. In the present study the differences in physiological responses to exercise between AP and UP could arise also from the lack of subject's familiarization with the aero-handlebars. This mechanism has been suggested previously by Johnson and Schultz (14). On the one hand, for the trained cyclists of this study, a work rate at 70% of $\dot{V}O_2$max might have determined no important constraint in AP in spite of the lack of familiarization in this position.

Mean hip angle variation

The difference in physiological responses to cycling between the three riding positions could be explained by the differences in rachis flexion (i.e. difference in mean hip angle). Heil et al. (12) showed that the cardiorespiratory responses to 10 min cycling exercise at 73% of $\dot{V}O_2$max were dependent on the mean hip angle. These authors investigated the effect of seat-tube angle variation on cardiorespiratory variables. They observed that $\dot{V}O_2$, H_R and $\dot{V}_E$ decreased significantly by 2.5, 2.2 and 4.5%, respectively, from a 69° to 83° seat-tube angle variation which determined 11° increase in mean hip angle (12). This mean hip angle variation of 11° is similar to the variation in trunk flexion from AP to DP and from DP to UP. However, in the study of Heil et al. (12), changing the riding position by changing the seat tube angle also caused changes in ankle plantar flexion as well as changing the fore-aft position of the lower limb relative to the position of the ergometer crank axis. These changes could influence the application of the force on the pedals (13). In the present experiment, the mean hip angle depended only upon trunk flexion and the lower-limb orientation was unchanged. However, the power produced in the ankle joint is less than that able to be produced in the hip joint (30). Heil et al. (12) have not speculated on why mean hip angle should influence $\dot{V}_E$. In this study, it could be suggested that the changes in mean hip angle which determined mainly changes in the trunk position could alter alignment and geometry of the upper respiratory tract and therefore the re-

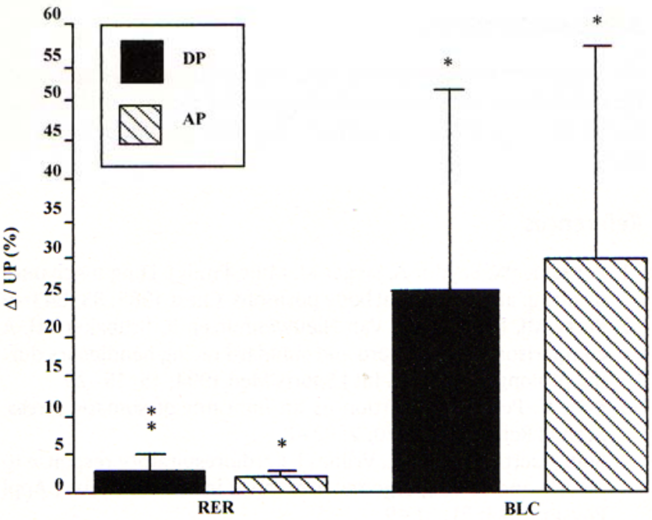

Fig. 2 Mean changes (Δ) normalized with respect to upright position (UP) in respiratory exchange ratio (RER) and blood lactate concentration ($[La]_b$, Mm) for dropped position (DP) and aero position (AP). *: significant difference from UP at $p < 0.05$ and **: significant difference from UP at $p < 0.01$. (Statistical analysis performed on the non-transformed data).

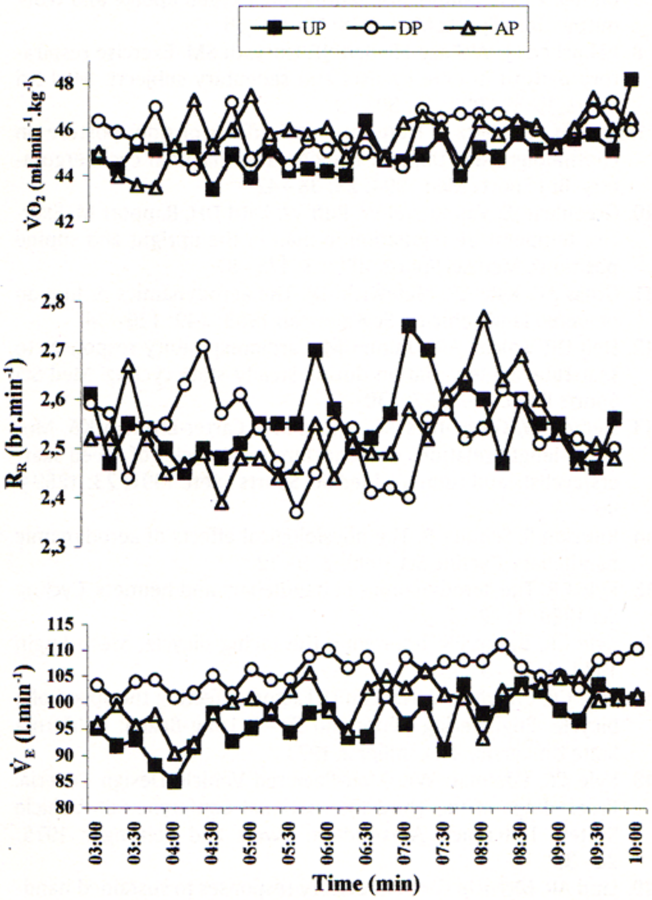

Fig. 3 Representative on-line records for oxygen uptake ($\dot{V}O_2$), ventilation ($\dot{V}_E$) and respiratory rate (R_R) related to time (from the 3rd to the 10th min of the exercise bouts) for each of the positions studied (upright position: UP, dropped position: DP, aero position: AP) from three different subjects.

spiratory mechanics. Thus, each position could determine its own respiratory mechanics, and could influence $\dot{V}_E$.

Ventilatory responses

In the present study, the significant difference in $\dot{V}_E$ observed between UP and DP is consistent with the finding of Heil et al. (12) and Faria et al. (7). The greater $\dot{V}_E$ observed in DP was not related with difference in metabolic demand and in $\dot{V}CO_2$. However, the higher $\dot{V}_E$ for DP was associated with a higher RER and $[La]_b$. pH remained constant at 7.38 in the three riding positions. This could suggest that the metabolic acidosis was better compensated for DP. While the change in RER between UP and DP can be related to a change in $\dot{V}_E$, the relative increase in RER observed for AP in comparison with UP is less clear. Indeed, the trunk flexion in AP determined a light but no significant increase in $\dot{V}_E$. When compared to UP, the change in $\dot{V}_E$ in DP was associated with similar change in V_T/T_I which has been proposed to reflect the intensity of central respiratory drive (20,21,24). The hyperventilation linked to the increase in V_T/T_I was previously reported in a study conducted in elite cyclists during short-term incremental exercise bouts until exhaustion (8). This hyperventilation could also be linked to change in pulmonary impedance related to the riding position. Indeed, two studies (1,22) reported an effect of body posture on respiratory impedance and suggested that different changes in body position could be associated with changes in the internal mechanical load of breathing. These results suggest that the increase in ventilatory response to cycling with DP could be explained by a greater activation of central respiratory drive and/or a lower pulmonary impedance.

Respiratory mechanics

In this study, when comparing UP to DP, the positive correlation found between $\Delta\dot{V}_E$ and ΔR_R and the negative correlation found between $\Delta\dot{V}_E$ and ΔV_T suggest that the abdominal compression which was expected when the trunk is tilted forward in DP hampers the work of the diaphragm. The increase in $\dot{V}_E$ occurred with both an increase in R_R and a decrease in V_T. Therefore, the abdominal compression altered respiratory mechanics, limited lung volume, and increased respiratory drive. These results were consistent with previous studies which compared exercise in rowing with cycle exercise in UP (4,6,29). The limited lung volume observed in the rowing position was explained by a greater rachis flexion and work of the upper limbs during rowing.

Respiratory timing

T_I/T_{Tot} remained unchanged in the three rider positions. This suggests that the inspiratory duty cycle, which is a pure index of the respiratory timing (21), was not altered by the trunk flexion. This is in line with previous studies (2,23) which did not find any T_I/T_{Tot} difference between UP and AP.

Energy requirement and static muscular activity

In this study, no significant difference in $\dot{V}O_2$ and H_R was found between the three riding positions. These results were in line with previous studies which failed to find any difference between the positions in $\dot{V}O_2$ (2,14,27) and H_R (14) at submaximal work rates and any difference in $\dot{V}O_2$ (9,23,31) and H_R

(7,9,23) at maximal work rates during short-term incremental exercise bouts. This suggests 1) in DP and AP, the change in mean hip angle and to maintain the specific position on the flexed elbow joints (determining a larger involvement of the joint stabilizing muscles) have not caused significant changes in energy requirement and in H_R, 2) the static muscular activity of the upper limb muscles which support the weight of the trunk tilted forward in DP and AP has not determined significant change in H_R and in $\dot{V}O_2$. Thus, when compared to UP, DP and AP don't limit one's ability to use the trunk, shoulder and arms as a base of support from which to push on the pedals during cycling. On the one hand, it has been reported that AP caused a 15% significant decrease of the aerodynamic drag when compared to DP (15). On the other hand, a recent study (26) conducted outdoors on cyclists in full exercise at 40 km · h^{-1} demonstrated that the reported aerodynamic advantage of AP produced a small (2%) but significant reduction in $\dot{V}O_2$ when compared to DP. Based on these two studies, since a change of aerodynamic drag automatically causes an identical change of the required power output, it would be expected in laboratory conditions (i.e. no drag effect) an increase in $\dot{V}O_2$ in AP close to 13%. This expectation is not in line with the present and previous measurements performed in laboratory.

Rating of perceived exertion

In this study, DP was perceived as more tiring than UP. This finding could be due to the degree of activation of the upper body stabilizing muscles and those of the elbow joint in the different riding positions. From this point of view, DP represents the more difficult position to maintain. Moreover, $[La]_b$ was significantly increased in DP as compared to UP. However, as compared to UP, in spite of the significant increase in $[La]_b$ in AP, RPE was not altered by the trunk flexion. In UP, DP and AP, the mean values for RPE at the mean values for $[La]_b$ were in agreement with a previous study (28). These results suggest that when compared to UP, the higher RPE in DP can be associated with the higher increase in $[La]_b$ in DP. Moreover, the larger changes in ventilatory and metabolic variables observed in DP could also alter RPE in this position.

Conclusion

The focus of this study was to determine the effect of cycling position on the ventilatory and metabolic responses of competitive cyclists at submaximal work rate. Although the ventilatory and metabolic responses and RPE were higher in DP when compared to UP, these changes have not been found between UP and AP. The present findings showed that the trunk flexion was not directly associated to changes in physiological variables. Thus, at moderate cycling speeds outdoors, when aerodynamic drag is low, UP appears to be the more suitable position. On the other hand, at high speeds (from 11 m · s^{-1}), when aerodynamic drag becomes predominant, AP which causes an unchanged RPE, appears to be the best position in terms of energy expenditure and performance, considering that the respiratory muscles O_2 consumption as a fraction of total $\dot{V}O_2$ averaged ~4–5% and does not increase appreciably as a portion of the total $\dot{V}O_2$ when exercise intensity increases (5).

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