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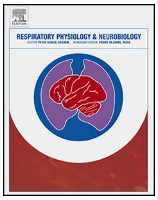

Ventilatory efficiency and breathing pattern in world-class cyclists: A three-year observational study

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ABSTRACT

The purpose of this three-year observational study was to analyze the ventilatory efficiency and breathing pattern in world-class professional cyclists. Twelve athletes (22.61 ± 3.8 years; 177.38 ± 5.5 cm; 68.96 ± 5.5 kg and VO_{2max} 75.51 ± 3.3mL kg^{-1} min^{-1}) were analyzed retrospectively. For each subject, respiratory and performance variables were recorded during incremental spiroergometry: oxygen uptake (VO_2), carbon dioxide output (VCO_2), pulmonary ventilation (VE), tidal volume (Vt), breathing frequency (f_R), driving (Vt/Ti), timing (Ti/Ttot), peak power output (PPO) and maximum oxygen uptake (VO_{2max}). Ventilatory efficiency (VE/VCO_2 slope) was calculated from the beginning of exercise testing to the second ventilatory threshold (VT_2). The VE/VCO_2 slope was unaffected during the study period (24.63 ± 3.07; 23.61 ± 2:79; 24:89 ± 2:61) with a low effect size (ES = 0.04). The PPO improved significantly in the third year (365 ± 33.74; 386.36 ± 32.33; 415.00 ± 24.15) ($p < 0.05$). The breathing pattern variables, Vt/Ti and Ti/Ttot, did not change significantly over the three year period (ES = 0.00; ES = 0.03 respectively). These findings suggest that changes in cycling performance in world-class professional cyclists do not modify breathing variables related to the control of ventilatory efficiency.

1. Introduction

Carbon dioxide (CO_2) is produced in cellular metabolism and expelled into the atmosphere by ventilation (VE), but during this process CO_2 plays a fundamental role in the regulation of bodily pH, vascular tone (Gilbert, 2005) and in the ventilation control (Milsom et al., 2004). The relationship between the rate of CO_2 output (VCO_2) and VE in different circumstances has been widely described as a measurement of breathing efficiency (Arena et al., 2007b; Arena et al., 2008; Sun et al., 2002) at a given metabolic rate. During incremental effort, the slope of the linear relationship between VE and VCO_2 (VE/VCO_2 slope or $DeltaCO_2$) is the most widely used method to evaluate ventilatory efficiency (Arena et al., 2007b; Brown et al., 2013; Schneider and Berwick, 1998; Sun et al., 2002; Ukkonen et al., 2008).

The VE/VCO_2 slope has been commonly used in patients suffering from congestive heart failure (Arena et al., 2007a,b; Ingle et al., 2007; Laveneziana et al., 2010; Robertson, 2011) as well as in healthy subjects (Sun et al., 2002). It is well established that the values of the VE/VCO_2 slope vary from 19 to 32 in healthy subjects (Sun et al., 2002), with values exceeding 34 considered abnormal (Arena et al., 2007a,b) or indicative of the inefficiency of the respiratory system (Brown et al., 2013). The large variability in VE/VCO_2 slope could be an inborn characteristic but it could also be explained by the lack of consensus of measurement methods. Thus, differences in the VE/VCO_2 slope arise depending on whether it is measured from rest to VT_2 or from rest to the maximal work load.

In trained athletes, the VE/VCO_2 slope has not been widely studied and its relationship with sport performance is unclear. It could be possible that two athletes had different values of equivalent of CO_2 (VE/VCO_2) to the same metabolic rate, but they show the same VE/VCO_2 slope throughout the entire incremental test. In this case, they have different efficiency to a given level but the same global efficiency because they need the same increase in VE for every increase of 1 l min^{-1} in CO_2 production (VE/VCO_2 slope) during the incremental test. It could be possible that the high demands of elite cycling promote a lower VE/VCO_2 slope, involving a lower increase in VE for a given increment in VCO_2. Conditions where the CO_2 production is elevated, such as cycling, seems to play an essential role in the ventilatory control (Milsom et al., 2004). The ventilatory efficiency control could change over time in presence of a large amount of training and competition as it happens with

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others respiratory and performance variables (Lucia et al., 1998; Sallet et al., 2006).

Accepted that the VE/VCO_2 slope in normal subjects is a marker of ventilatory sensitivity, there are three possible mechanisms by which respiratory efficiency could change with training. One is through changes in the dead space (VD) at low power output (Wood et al., 2008); the other is a better mechanical performance of respiratory muscles (Sheel, 2002) and the third is an improved sensitivity of chemoreceptors (Babb et al., 2010).

It may also be expected that changes in the VE/VCO_2 slope with training could be related to improvements of breathing control by a more effective breathing pattern. Unlike ventilatory efficiency, the breathing pattern has been widely studied in athletes (Benchetrit, 2000; Lucia et al., 1999; Lucia et al., 2001; Scheuermann and Kowalchuk, 1999). A simple way to analyze the breathing pattern is to evaluate the relationship between the tidal volume (Vt) and breathing frequency (f_R) (Milic-Emili and Cajani, 1957). However, since the 1970s (Milic-Emili, 1982; Milic-Emili and Grunstein, 1976), it has been known that VE can be decomposed into the product of two components which offer more information: (a) central inspiratory activity, known as "driving" and expressed as the relationship between Vt and inspiratory time (Vt/Ti) and (b) the inspiration-expiration alternation, known as "timing", and expressed by the relationship between Ti and the total duration of the breathing cycle (Ti/Ttot). The analysis of all these variables (VE, Vt, BF, Vt/Ti, Ti/Ttot) is nowadays the most widely-used method to evaluate the breathing pattern in patients (Beltrão et al., 2015), sedentary subjects (Benchetrit, 2000) and athletes as well (Lucia et al., 2001; Lucia et al., 2003).

The studies which evaluated the VE/VCO_2 slope in healthy people were performed with sedentary or moderately trained subjects but not in highly trained athletes. In addition, we are not aware of any articles dealing with longitudinal VE/VCO_2 slope observations in athletes. It is usually difficult to study cyclists of the highest level due to the number of hours of training and competition they undergo over the competitive seasons, but thanks to the evaluations carried out by our research group over several seasons with a UCI-Pro Tour team (Santalla et al., 2009), we were able to analyze all these respiratory variables of interest in world-class cyclists.

We hypothesized that the high demands of professional cycling could induce changes in ventilatory efficiency, measured as the VE/VCO_2 slope, in world-class cyclists over a three-year period. If true, we would expect that changes in the VE/VCO_2 slope are related to changes in breathing pattern.

Therefore, the purpose of this study was to perform a retrospective longitudinal evaluation of the ventilatory efficiency and breathing pattern in world-class cyclists.

2. Material and methods

2.1. Subjects

A total of 42 male world-class professional cyclists, tested during the same period of the season in the same laboratory for at least five seasons, were retrospectively analyzed to select those for whom consecutive evaluations were available over a period of at least three years. Finally, 12 cyclists (starting age 22.61 ± 3.8 years; height 177.38 ± 5.5 cm; body weight 68.96 ± 5.5 kg and 76.92 ± 5.9 mL kg^{-1} min^{-1}) were included who had participatedannually in at least one of the three-week stage races (Giro d'Italia, Tour de France and Vuelta a España) or were evaluated at least two times consecutively over three years at the same time point in the season. Some of the subjects were among the best cyclists in the world (one winner of the Tour de France, one winner of the Vuelta a España and first in the annual ICU world ranking, one three-time Tour de France Podium, two Vuelta a España Podium, one Junior World Time Trial Champion, and two one-week stage race winners). All subjects provided written informed consent before testing. The study has been approved by the ethics committee of the Pablo de Olavide University (Seville).

2.2. Exercise test

Tests were always conducted during the first phase of the cyclists' competitive season. All incremental exercise tests have been performed on the same electromagnetically braked cycle ergometer. This ergometer allowed the subjects to choose their own pedal frequency and to adopt a position similar to that on their bicycles (Orion S.T.E., Toulouse, France). The distances and dimensions for saddle, handlebars and connecting rod were monitored and remained constant during the entire test period. The test was started at a power output (PO) of 100 W, after which PO was increased by 50 W every 4 min until exhaustion. This exercise protocol has already been used in previous research (Fernandez-Garcia et al., 2000). The freely chosen pedaling cadence generally ranged from 77 to 115 revolutions per min (rpm). Heart rate was monitored using radio-telemetry (Sport tester PE 4000; Polar, Kempele, Finland). Ventilation and respiratory gases were measured continuously and the highest 30-s VO_2 value was considered as VO_{2max}. VO_2, VCO_2, VE, Vt, f_R, Ti, Te and Ttot were measured breath by breath (BxB) using a gas analyzer (Vmax 29; Sensormedics, Yorba Linda, CA), which was calibrated before every exercise session. During the data collection period (three years), neither the cycle ergometer nor the gas analyzer was replaced and all the equipment passed the maintenance procedures recommended by the manufacturers. The ergometer was calibrated by the manufacturers annually. In addition, all the tests were performed under similar ambient temperature conditions (20–24C and 45%–65% relative humidity).

2.3. Ventilatory efficiency and breathing pattern

The ventilatory efficiency of each subject was calculated from the slope of the relationship between VCO_2 and VE during each test. To exclude the influence due to respiratory compensation for acidosis during highly intensive exercise, the VE/VCO_2 slope was determined from the beginning of the test until the second ventilatory threshold (VT_2). The breathing pattern was evaluated by the analysis of Vt, f_R, Vt/Ti and Ti/Ttot. The value of the slope representing the relationship between VE and Vt/Ti during each test (the driving slope) was used to test the central component.

2.4. Statistical analysis

The data is expressed as mean ± SD for each variable. The normality of the data was checked by means of the Shapiro-Wilk test. The homogeneity of variance was evaluated by Leveneís test. To compare the values obtained for each variable during the three-year observation period, one-way ANOVA with repeated measurements and the Friedman F-test (nonparametric conditions) were used. When significant differences were found, the Bonferroni test was used as a post hoc test. Effect sizes (ES) were also calculated using Eta-Squared. Intra-class correlations (ICC) and Pearson correlation coefficient (Pearson-r) were used to determine the reproducibility of measurements over time for VE/VCO_2 slope, VO_{2max} and PPO.Correlation analyses were carried out between VO_{2max}, VE/VCO_2 slope and PPO. The level of significance was set at $p < 0.05$ for each statistical analysis.