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Evolution of physiological and haematological parameters with training load in elite male road cyclists: a longitudinal study

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Aim. **The aim of this study was to describe and evaluate physiological parameters as a control tool for the monitoring of training in a group of elite cyclists during one season of training.**
Methods. **The study is divided into two periods (winter or "volume" mesocycle and spring or "intensity" mesocycle) between the tests that they carried out in the laboratory, consisting of a ramp test to exhaustion (work load increases 25 $W \cdot min^{-1}$) and a maximal lactate steady state (MLSS) test on a cycle ergometer. Macronutrients and hematological variables were recorded during the test periods as were the volume and the intensity of training sessions during the whole period of the study.**
Results. **The physiological data were similar to those previously reported for professional cyclists (~450 Watts, ~78 $mL \cdot kg^{-1} \cdot min^{-1}$) and the values for the MLSS also agree with previous studies (~250 Watts). Subjects improved the first ventilatory threshold (VT_1) (~52% to ~60% $\dot{V}O_{2max}$) and the second ventilatory threshold (VT_2) (~82% to ~87% $\dot{V}O_{2max}$) after the first period of training even though its low intensity focused on the performance of VT_1 (77% training in "zone 1", under VT_1). The MLSS improved after the first period (~225 to ~250 Watts) and remained high in the second (~255 Watts). High levels of creatine kinase (~230 $U \cdot L^{-1}$) and urea (37 $mg \cdot L^{-1}$) were found, also a decrease in hemoglobin values (~15.4 to ~14.7$g \cdot dL^{-1}$).**
Conclusion. **The high level reached by the subjects after the first period of training suggests that two effort tests could be enough to plan training. On the other hand, the decrease in some red blood cell and nutrition parameters suggests that there should be greater control over them during the season.**

KEY WORDS: Training - Cycling - Hematological tests - Physiological processes.

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The step before becoming a professional cyclist usually involves competing in the "sub23-elite" category of the international Cycling Union (former "amateur" category). These young elite cyclists cover approximately 30 000 km each year and their season includes 50-90 days of competition. The main difference with professional cycling is that elite main competitions are only 1-day competitions with some 5-day stage races, normally of lesser distances to be covered each day. Nevertheless, the intensity of such extreme races can be greater than professional races. Thus the endurance training and physiological characteristics of both groups are similar as has been reported before.[1-4]

The training control of such a demanding sport is a crucial tool for coaches' feedback and includes many laboratory and field testing variables.

The training season of these athletes normally begins at the end of November and ends in October (10-11 months) with an extended competition main period normally lasting from July until September. Some other

TABLE I.—*Characteristics of the subjects in each period.*

	1st visit	2nd visit	3rd visit
Age (years)	20±1.9	20±1.9	20±1.9
Body mass (kg)	68.6±1.9	67.7±1.7	67.4±1.8
Height (cm)	176.8±1.9	176.8±1.9	176.8±1.9
Percentage body fat (%)	8.2±0.4	7.6±0.4*	7.4±0.3*
VC (L)	5.9±0.3	5.8±0.2	5.9±0.2
MVV ($L \cdot min^{-1}$)	212.3±12.2	202.1±9.7	202.3±10.1
Resting HR ($beats \cdot min^{-1}$)	61.6±2.5	56.5±2.7	52.5±1.8*

Data are shown as means ± standard errors of the means. VC: vital capacity; MVV: maximal voluntary ventilation; HR: heart rate.
*P<0.05 for 2nd or 3rd visit *vs* 1st visit to the laboratory.

TABLE II.—*Training volume and intensity during each mesocycle.*

	Winter mesocycle	Spring mesocycle
Volume (h)	211.31±0.57	260.34±0.6*
Volume zone 1 (%)	77.7±0.3	69.9±0.5*
Volume zone 2 (%)	19.7±0.6	22.1±0.4
Volume zone 3 (%)	2.4±0.3	8.1±0.2*

Data are shown as means ± standard errors of the means. *P<0.05 for Spring *vs* Winter period.

less important competition events start in spring and are usually 1 - day competitions over weekends. The cyclists enrolled in amateur cycling compete for a cycling team and by demonstrating their progress hope to have a professional contract before they are 23 years of age.

The extreme professionalisation of the sport has made increasing demands even on pre-elite categories. Therefore, physiological training control is now a necessary tool, so that coaches can provide feedback for their athletes.

The aim of this longitudinal study was to analyze the adaptation processes of physiological and hematological variables in a full training season of elite cyclists.

Materials and methods

Subjects

Fourteen male road cyclists competing in the "elite sub23" category of the International Cycling Union participated in the study. In order to be included, they had to meet the following criteria. They had to: 1) have at least 2 years experience of prior competition; 2) be enrolled in a licensed amateur team; 3) have at least 1 year's familiarization with laboratory tests; 4) be following an identical training plan under the supervision of the technical direction of the Madrid Cycling Federation.

The subjects were in good health, as determined by a normal physical examination (including electrocardiogram). The subjects' characteristics are shown in Table I.

Study protocol

Informed consent was obtained from each participant in accordance with the guidelines of the World Medical Association regarding human investigation as outlined in the Helsinki declaration. Each subject was tested 3 times during the study corresponding to the "start of the season" (fall: November), end of the "volume mesocycle" (fall: February) and end of the "intensity mesocycle" before the start of the main competition period (June) of the sports season. During each week of tests, they had a blood test on Monday, anthropometry and ergoespirometry tests on Tuesday, nutritional intake tests from Monday to Friday and the maximal lactate steady state (MLSS) test on Friday.

Training

For the two periods (mesocycles) defined between the tests training variables were recorded every day and the means ± standard errors of the means (SEM) of the group are shown in Table II. The volume (hours) expresses the total training time expended in each period, and the intensity is measured in hours of training at 3 different heart rate zones: 1) below first ventilatory threshold (VT_1) or zone 1; 2) between VT_1 and second ventilatory threshold (VT_2) or zone 2; and 3) above VT_2 or zone 3. The percentage of training at each zone is shown in Figure 1. All data was recorded on each subject with a heart rate telemeter (Polar S720i, Polar Electro OY, Finland), that recorded continuously every 5 s during the training sessions. Competition days were also included in the training log.

Anthropometric variables

For the percentage body fat calculation, 6 skinfolds were measured: triceps, subscapular, supraspinal, abdominal, calf and thigh and the following formula was applied:[5]

$$\% \text{ Body fat} = (((\Sigma 6 \text{ skinfolds}) \cdot 0.097) + 3.64) \cdot 100^{-1}$$

Body mass and height were also calculated following the procedures described by Carter *et al.*[5]

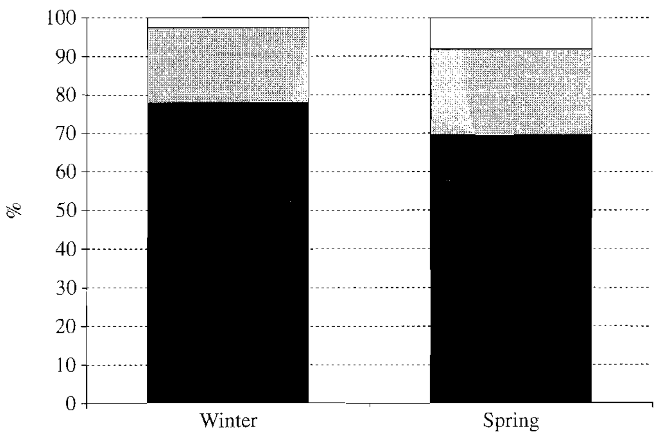

Figure 1.—Percentage of work in each intensity zone. Black represents zone 1, grey zone 2 and white zone 3.

Exercise tests

Each test was performed on a cycle ergometer (Jaeger ER800, Erich Jaeger, Germany). The maximal test followed a ramp protocol until exhaustion starting at 0 Watts and increasing the load to 25 Watts·min^{-1} and keeping a pedaling rhythm between 70 to 90 rev·min^{-1}. Each exercise test was terminated either: voluntarily by the subject, when pedaling rhythm could not be maintained at 70 rev·min^{-1} (at least) or when the established criteria of test termination were met.

For MLSS determination a double intensity test was used.[6] This consisted of two exercises of 30 min at a previously established intensity with an intervening rest period of 45-min sitting on an arm chair. Tests were performed in similar environmental conditions (21 °C to 24 °C, 45% to 55% relative humidity).

Gas exchange variables

Gas exchange data were obtained during the exercise tests using an automated breath-by-breath system (Jaeger Oxicon Pro®, Erich Jaeger, Germany). Calibration was carried out before each test with the necessary environmental adjustments. Data were recorded for the analysis with an average of 8 respirations by the software Lab Manager V4.53a.

Blood sampling and analysis

For lactate concentration (La) determinations, fingertip samples of capillary blood were taken and analyzd by photometry with Dr. Lange LP-20 (Bruno Lange, Germany) equipment.

The hematological variables were determined after the weekly rest day by the specialist of the Pharmacy Faculty of the Complutense University of Madrid. Serum from blood resting samples was analyzed using RA-500 (Bayer, Germany) equipment in accordance with the instructions and protocols of the Spanish Clinical Chemist Society (SEQ).

Nutritional analysis

For the evaluation of food intake, a 5-day survey was completed by the subjects during each of the 3 weeks of testing. Data were analyzed using Nutritionist IV (v4.1) software to obtain the macronutrient data.

Statistical analysis

One way repeated-measure analysis of variance (split-plot ANOVA) was used to compare the mean variables recorded over the three periods. Previously, a Mauchly test proved the sphericity of the sample. Software SPSS (v11.5) was used to handle the data. Results are expressed as means ± SEM. The level of significance was set at 0.05.

Results

Training

Training characteristics are shown in Figure 1 and Table II. The total volume is significantly higher ($P<0.05$) in the spring mesocycle than in the winter mesocycle. As for training intensity, significant differences were found in percentage of work in zone 1 and 3 ($P<0.05$) of the spring cycle than in the winter one and no differences were found for the percentage of work in zone 2.

Effort tests

Physiological variables from effort tests are shown in Table III. There is a significant increase ($P<0.05$) of power output in the 2nd and 3rd visit to the laboratory compared with the 1st visit as measured by VT_1 and VT_2. For the maximal power output (W_{max}) values these differences were not significant after the 3rd visit. A significant decrease ($P<0.05$) in maximum heart rate (HR_{max}) is shown after the 3rd visit compared with the

TABLE III.—*Physiological variables from the effort tests.*

	1st visit	2nd visit	3rd visit
W_{max} (Watts)	429±12.5	463±13.4*	448±18.2
HR_{max} (latido·min^{-1})	197.8±3.1	193.3±3.6	189.3±3.7*
$\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1})	73.1±1.8	77.6±1.4*	80.5±1.8*
[La]max (mmol·L^{-1})	11.3±1.1	12±1.1	11±1
W_{VT1} (Watts)	206±11.2	252±10.8*	254±13.5*
HR_{VT1} (beats·min^{-1})	140.6±3.4	143.6±3.8	141.6±3.5
$\dot{V}O_{2VT1}$ (mL·kg^{-1}·min^{-1})	38.1±1.7	47.2±1.5*	50.4±1.9*
$[La]_{VT1}$ (mmol·L^{-1})	1.9±0.2	1.8±0.1	1.8±0.1
$\dot{V}O_{2VT1}$ (%$\dot{V}O_{2max}$)	52±2.1	60±1.8*	62±1.7*
W_{VT1} (Watts)	339±11.1	378±8.7*	377±11.7*
HR_{VT2} (beats·min^{-1})	178.6±2.9	179±3.3	176.8±3.5
$\dot{V}O_{2VT1}$ (mL·kg^{-1}·min^{-1})	60.3±1.8	68.5±1.9*	72.9±2.3*
$[La]_{VT2}$ (mmol·L^{-1})	5.09±0.6	5.56±0.6	5.22±0.5
$\dot{V}O_{2VT1}$ (%$\dot{V}O_{2max}$)	82.5±1.7	87.9±1*	90.1±1.4*

Data are shown as means ± standard errors of the means. W: power output; HR: heart rate; VO: oxygen uptake; La: lactate concentration. *P<0.05 for 2nd or 3rd visit *vs* 1st visit to the laboratory.

TABLE IV.—*Physiological variables from the maximal lactate steady state tests.*

	1st visit	2nd visit	3rd visit
Age (years)	20±1.9	20±1.9	20±1.9
W_{MLSS} (Watts)	225±9.9	249±11.3^{a}	255±10.6*
HR_{MLSS} (beats·min^{-1})	150.1±5.5	147.4±4.4	149.8±4.5
$[La]_{MLSS}$ (mmol·L^{-1})	2.5±0.2	2.7±0.3	2.6±0.3

Data are shown as means ± standard errors of the means. W: power output; HR: heart rate; La: lactate concentration.
*P<0.05 for 2nd or 3rd visit *vs* 1st visit to the laboratory.

first one. No changes were found for HR at VT_1 and VT_2 in any of the visits. Oxygen uptake ($\dot{V}O_2$) was significantly increased (P<0.05) for the three times of each test (maximum, VT_1 and VT_2) in the 2ud and 3rd visit compared with the first one. No changes were shown in La and finally the threshold position (%$\dot{V}O_{2max}$) significantly improved (P<0.05) after the 1st visit with no difference between the 2nd and 3rd visit

Maximal lactate steady state tests

Physiological variables from the MLSS tests are shown in Table IV. Significant increases (P<0.05) were obtained for the power output (W_{MLSS}) at MLSS after the 1st visit with no changes in heart rate and La.

Blood tests

Hematological variables are shown in Table V. There is a significant decrease (P<0.05) in hemoglobin concentration (Hb) after the 3rd visit compared with the first one with no changes in the remainder of the red blood cell profile and iron related parameters. Also a significant increase (P<0.05) in urea values is shown after the 3rd visit against the first one with no changes in creatine kinase (CK) profile.

TABLE V.—*Hematological variables.*

	1st visit	2nd visit	3rd visit
ERIT (×10×6·µL^{-1})	5.1±0.1	5±0.1	4.9±0.2
Hb (g·dL^{-1})	15.4±0.3	14.7±0.3	14.7±0.4*
HTC (%)	48.3±0.8	47.6±0.8	46.7±0.9
Urea (mg·L^{-1})	30.4±3.5	37.6±2.4	37.1±2.9*
H (µg·dL^{-1})	109.1±10.8	121.3±12.9	118.9±15.4
Ferritin (ng·mL^{-1})	163.8±23	132.5±14.7	138.4±18.4
CK (U·L^{-1})	216.0±59.2	220.9±78.5	231.4±60.5

Data are shown as means ± standard errors of the means. ERIT: ; Hb: hemoglobin; HTC: ; H: ; CK: creatine kinase.
*P<0.05 for 2nd or 3rd visit *vs* 1st visit to the laboratory.

TABLE VI.—*Nutritional variables.*

	1st visit	2nd visit	3rd visit
CH (%)	52.5±2.1	46.4±2.9*	53.4±2.4**
Lipids (%)	29.5±1.8	35.1±2*	27.6±2**
Proteins (%)	17.9±0.9	18.3±1.1	17.8±1.3

Data are shown as means±standard errors of the means. CH: carbohydrates intake. *P<0.05 for 2nd or 3rd visit *vs* 1st visit to the laboratory. **<0.05 for 3rd visit *vs* 2nd visit to the laboratory.

Nutrition

Nutritional variables are shown in Table VI. There is a significant decrease (P<0.05) in the carbohydrates intake (CH) of the 2nd visit compared with the first, one which returns to the same reading at the end of the 3rd visit (P<0.05). Also the lipids intake increases (P<0.05) at the 2nd visit and decreases (P<0.05) at the 3rd visit compared with the second. No changes are shown for the protein intake.

Discussion

The increasing professionalization and the dedication needed to achieve this level has made physiological knowledge of sport performance more and more important for coaches. Recent reviews have described the physiological characteristics of professional cycling,[1, 2, 7] but there is still little known about the physiological changes resulting from endurance training of highly trained cyclists.[8-10] Following the group characteristics common description, the group of elite cyclists monitored in this study could be compared with professional uphill specialists.[2] In fact, 7 of the subjects have already reached the professional category and are currently competing in the international pro-tour races. The decrease in the percentage of body fat is also compatible with previous data for these group specialists.[1]

We could find only two previous longitudinal studies,[8, 10] which have monitored training volume and intensity (focusing on coaches' feedback for training) and have investigated 'adaptation' explanations for the results. Novel findings in our study disagree with some of those previously published and could be dependent on the age of the subjects, as explained below.

Exercise tests

The maximal data obtained by the subjects (~463 Watts, ~80 mL·kg^{-1}·min^{-1}) indicate the quality of the sample and are comparable with those previously reported for professional cyclists. As they had to follow an identical training plan under the supervision of the technical direction of the Madrid Cycling Federation, the final sample comprised the best elite cyclists of the region. This could explain the high levels reached by the subjects and the homogeneity in their performance.

The changes after the 1st visit can easily been explained by the high volume of training carried out during the winter mesocycle (~211 h), but the data are not dissimilar after the spring mesocycle even though the total volume is significantly higher (~260 h). Previous studies[10] have explained this result as dependent on reaching a physiological ceiling suggesting that after reaching such high central values further changes would focus on peripheral variables. Another explanation could be the accumulated volume of training occurring after almost 8 months of measurement without any decrease in competition (the competition cycle would start after the last measurement and continue for a further 3 months).

A global increase of 8% in $\dot{V}O_{2max}$ is higher than others reported in the literature for this sport[7] and may be due to the young age of the subjects who still have great performance potential. Although $\dot{V}O_{2max}$ is an integration variable there are no other peripheral variable results, which could explain these changes. The decrease ($P<0.05$) in the basal heart rate (~61-52 beats·min^{-1}) presumes cardiac adaptations that could positively influence the first part of the Fick equation (Q) for $\dot{V}O_{2max}$.

A positive displacement of VT_1 can also be seen after the 2nd visit (8-10%). This accords with other studies[11] for elite triathletes, but is not reported in those for professional cyclists whose subjects had the optimal performance position in both thresholds throughout the training season.[9]

From the data for HR and La it is hypothesized that a single effort test at the start of the season should be enough to calculate the intensities of training with other kinds of submaximal tests to measure changes during the year.

The high volume of aerobic training (~90% work at zone 1 + zone 2) carried out over the spring mesocycle is a possible reason for the maintenance of VT_1 values (~252 Watts and ~60% $\dot{V}O_{2max}$) until the 3rd visit. It seems that training in zone 3 is mostly maintained by competition. This could conceal some of the expected performances for the anaerobic endurance indicators.

A similar response is shown for VT_2 measured variables with a surprising performance after the winter mesocycle where only ~22% of the training was carried out between zone 2 and 3. Again, no changes were shown for HR and La.

Obtained values (~378 Watts and ~89% $\dot{V}O_{2max}$) are similar to those reported for professional cyclists.[2]

Maximal lactate steady state

From the results of the submaximal test, it is seen that the MLSS does not change during the season in HR and La. This observation conforms with previous studies.[12] At the same time, the load at which the subjects reached their steady state increased similarly to the rest of the variables obtained from the maximal tests.

It is not easy to find reference values in the literature for comparison with our group of subjects. Beneke *et al.*[13] presented average values of ~257.8 Watts at MLSS for a mixed group of cyclists and triathletes. Although these data are similar to the 3rd visit of our cyclists, we think that the double intensity test underestimates the MLSS. It was impossible for us to demonstrate this hypothesis by making different steady states over the obtained load from the double intensity test. Other mathematical approaches to the average intensity required to break the hour record suggest a 400-Watt burst of energy expenditure would be needed during that time.[1]

Blood

A decrease in red blood cell-related parameters has been observed in previous studies of endurance sports and is attributed to the increases in training volume.[14] Hb values <14 g·dL^{-1} have been associated with sports anemia.[15] Although our subjects had significant differences ($P<0.05$) only for the Hb values at the 3rd visit, all red blood cell related values had a tendency to decrease at every new visit.

High urea and CK values have also been related with processes used to increase the volume at anaerobic threshold, or zone 3 volume.[16] This could be an indicator of the high volume and intensity of training in our subjects, and suggests the need for control to avoid a future pseudoanemia process. Iron related parameters did not change through training in contrast with other studies.[17]

Nutrition

The energy used by a cyclist undergoing such a demanding level of training is very high (~327±34 KJ·kg^{-1}). The really important variable of their nutrition is CH. A 60-65% of CH intake in the diet has been recommended in the literature.[18] Low CH intakes have been associated with glycogen deposit depletion during a microcycle followed by overtraining characteristics if the lack of CH is not remedied.[19]

Our data are similar to those previously published for professional cyclists: 58±3% of CH intake, 13±0.8 protein intake and 30±3 of lipid intake[20] with changes throughout the season for the CH intake (~46-53%), which never reached the recommended values previously reported.

Conclusions

Our findings suggest that one or two effort tests during the season are sufficient within training programs, as no changes in HR occur during the season for the VT. It also emphasizes the need for blood and nutrition analysis to prevent the danger of overtraining in such a demanding sport.

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