**Intense endurance training on heart rate and blood pressure variability in runners**

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**ABSTRACT**

PORTIER, H., F. LOUSY, D. LAUDE, M. BERTHELOT, and C. Y. GUEZENNEC. Intense endurance training on heart rate and blood pressure variability in runners. *Med. Sci. Sports Exerc.*, Vol. 33, No. 7, 2001, pp. 1120–1125. Physical training with incomplete recovery times may produce significant fatigue. A study of cardiovascular responses showed that there is a sympathetic and a parasympathetic form of fatigue. **Purpose:** The purpose of this experimentation was to measure the effects of intense endurance training on autonomic balance through a spectral analysis study of the heart rate (HR) and systolic blood pressure (SBP). **Methods:** Eight elite runners were tested twice: after a relative rest period (RRP) of 3 wk and after an 12-wk intense training period (ITP) for endurance. At the end of each phase, the subjects were tested by means of a VO\textsubscript{2max} test and a tilt-table test. **Results:** The resting heart rate (HR) variability was lower \((P < 0.001)\) in the intensive training phase. Likewise, there were differences in the low-frequency \((0.04–0.150 \text{ Hz}; \text{LF})\) and high-frequency \((0.150–0.500 \text{ Hz}; \text{HF})\) components and the LF/HF ratio of the HR spectral analysis. The LF spectral power was significantly lower in the supine position \((P < 0.05)\) during ITP. Upright tilting was accompanied by a 22.6% reduction in HF values during the rest period, whereas in ITP the HF spectral power rose by 31.2% \((P < 0.01)\) during tilt, characterizing a greater parasympathetic system control. **Conclusions:** The spectral analysis of SBP in the high frequencies shows that the changes in cardiac parameters are coupled with a decrease in sympathetic vasomotor control \((-18\%)\) and a reduction in diastolic pressure \((-3.2\%)\) in the response to the tilt test at the end of ITP. Spectral analysis could be a means of demonstrating impairment of autonomic balance for the purpose of detecting a state of fatigue that could result in overtraining. **Key Words:** SPECTRAL ANALYSIS, AUTONOMIC BALANCE, HARD TRAINING, FATIGUE

Endurance training is accompanied by a significant fall in resting heart rate (HR) \(3,5,9,16,18,19,26\). This is certainly due to a reduction in intrinsic heart rate, linked to stabilization of the cell conduction system membrane, as well as a high degree of vagal control of the sinus node \(6,10,12,33\).

Data concerning adaptation of the cardiovascular system during endurance training are contradictory. According to some authors, training increases variability in heart rate, evidenced by greater energy lying flat in trained individuals than in those who are sedentary \(3,9\). They suggest a modification of vagal activity \(3,9\) with increased parasympathetic modulations. Others consider that the absence of variation in R-R interval confirms that respiratory sinus arrhythmia (RSA) does not vary \(16,18,20,26\). However, RSA may be reduced if vagal inhibition is markedly increased beyond a critical threshold \(3\). Decreased sympathetic activity could then come into play \(3\).

Physical training with incomplete recovery times may result in marked fatigue. Some authors have attempted to contrast two types of fatigue, on the basis of the study of cardiovascular responses: orthosympathetic type fatigue and parasympathetic fatigue \(1976,\text{ cited in }13\). Overtraining with an orthosympathetic dominant is believed to be characterized by an increase in resting heart rate (HR) and blood pressure (BP). This form occurs especially in young people involved in strength-speed activities \(1986,\text{ cited in }13\).

According to Kinderman and Kuipers \(1986,\text{ cited in }13\), the orthosympathetic type form could involve increased sympathetic neuroendocrine activity in response to prolonged and repeated stimuli by stress, including physical exercise. Kuipers does not seek to identify the origin of the parasympathetic form, but rather its apparent manifestation, and considers that the latter tends to reflect exhaustion of the autonomic nervous system in general.

The parasympathetic dominant form is believed to be characterized by increased parasympathetic activity and orthosympathetic inhibition, with a fall in BP and HR. This form occurs mainly in older people involved in endurance activities \(1986,\text{ cited in }13\).

Although the typology of fatigue according to autonomic nervous system status meets a physiologic reality, a study of cardiac variability provides an objective assessment of autonomic balance by analysis of frequencies. It is accepted that HR and systolic (SBP) and diastolic (DBP) blood pressures vary in the short term. Variations are influenced by a series of physiologic stimuli, which are often used to understand certain
aspects of cardiovascular control. Estimation of the involvement of autonomic balance in the regulation of HR and BP is possible using spectral analysis (1,3,6,10,11,23,27,31,33,34). This technique can reveal different frequency peaks, each reflecting a particular physiologic stimulus.

Regarding variability in HR, two characteristic peaks linked to autonomic balance status have been found. The first, situated between 0.04 Hz and 0.15 Hz (32), corresponds to Mayer waves (1) and appears to be linked to the combined activities of the sympathetic and parasympathetic systems (1,33). The second, situated between 0.15 Hz and 0.5 Hz (33), is synchronous with respiration and reflects vagal activity. In the case of HR, this waveband gives an indication of respiratory sinus arrhythmia (RSA) (7). In contrast, for SBP, peak low frequency corresponds to sympathetic activity whereas peak high frequency seems to be related to ventilatory mechanics (1,34).

Variability in blood pressure is more difficult to define. The very low frequencies (≤ 0.04 Hz) seem to be modified by vascular tone, endothelium factors, and thermoregulation influences (2,25). The low-frequency peak (0.07–0.15 Hz) seems to correspond to sympathetic activity and represents vasomotor tone marker (23,27).

There are a few available studies on physical exercise and the effects of training on variability in HR and BP. Experiments have used individuals undergoing endurance training for about 10 wk. Our study evaluated variability in HR and BP in a group of national class marathon runners having participated in their activity intensively for 15 yr. We compared two typical situations in the preparation of runners: first a period of relative rest and second a period of intensive training, followed by half-marathon or marathon competition. Our study could also be the way to demonstrate signs typical of intense fatigue. This involved a study of fatigue by changes in cardiovascular responses and their control by the autonomic nervous system during a dynamic orthostatic duress test (tilt test).

MATERIAL AND METHODS

The protocol used human subjects, during monitoring of the training of nine half-marathon and marathon runners. The study cohort consisted of six men and three women involved in competition running for the past 15 yr. Characteristics of subjects are described in Table 1. All participated in the study voluntarily after having been provided with information and given their consent in writing in accordance with ethics committee procedures.

One of the participants had to be withdrawn from the experiment because of too many premature ventricular contractions, which made it impossible to interpret the results of spectral analysis. Another was eliminated at the end of the experiment because of absence of variability of HR. When questioned, this volunteer admitted that he was on an antidepressant.

Recording data. A V̇O₂max test was done at the end of each training phase in parallel with the tilt test. The V̇O₂max test required subjects to run on a treadmill (Imbernon, Villerubanne, France). The test involved a succession of increments at 2-min intervals. At the end of each completed increment, speed was increased by 1 km·h⁻¹ until the subject was exhausted. Inspired and expired gases were measured every 20 s using a gas analyzer (SensorMedics, type 2900 z, The Netherlands) to obtain values of V̇O₂max. V̇O₂max is defined as the highest V̇O₂ value reached during exercise. Aerobic maximum speed is that of the last increment run completely.

Experimental protocol. The entire cohort was monitored throughout an athletics season. Two typical moments in the training of runners were selected. The first period was a relatively light training phase of 3 wk during which runners did twice-weekly training sessions of 45 min of endurance (20 km). The second period was an intensive preparation phase of 12 wk consisting of 9–10 weekly training sessions (130–150 km). A competition half-marathon or marathon followed this phase. Subjects were tested at the end of each period. These two periods were separated by a moderately intense training phase of 6 wk.

The tilt test was done under standard temperature conditions (20°C), in a dark, silent room. Subjects did their test at fixed times. There was an imposed respiratory rate of 12 per minute (0.250 Hz). They could regulate themselves using an audible signal. For the test under resting conditions, athletes did not train for the previous 72 h. Subjects were asked to abstain from tea or coffee drinks and to avoid eating just before or during the test.

HR and BP spectral analysis. Assessment of cardiac autonomic regulation was assessed in this study by the spectral analysis HR and BP variability. Limitations and advantages of using this method have been developed elsewhere (1). The BP signal was digitized using a 12-bit A/D converter at a rate of 500 Hz and processed by an algorithm based on feature extraction to detect and measure the characteristics of an arterial pressure cycle with its maximum in a 0.5-s window (Anapres V 1.2, Notocord system, France). SBP, MBP (mean blood pressure), DBP, and BP were stored. The evenly spaced (equidistant) sampling permitted direct spectral analysis of each distribution using a fast Fourier transform (FFT) algorithm on a 512-point stationary time series. This corresponded to a period of 4 min 16 s at this 2-Hz sampling rate. The following indexes of heart period variability were computed: total power (TP), spectral power in the low-frequency (LF; 0.04 Hz–0.15 Hz) and high-frequency (HF; 0.15 Hz–0.50 Hz) bands expressed in absolute values (in ms² and mm Hg²) as well as in normalized units, which represent the relative value of each power component in proportion to the total power minus the very low frequency (VLF; ≤ 0.04 Hz) component. Signal processing,
TABLE 2. Differences in maximal oxygen uptake (VO2max) between the relative rest period and the intensive training period.

<table>
<thead>
<tr>
<th></th>
<th>Relative Rest Period</th>
<th>Intensive Training Period</th>
<th>Diff (%)</th>
<th>P</th>
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<tbody>
<tr>
<td>VO2max (mL·min⁻¹·kg⁻¹)</td>
<td>72 ± 4.11</td>
<td>72.2 ± 4.13</td>
<td>+0.29</td>
<td>NS</td>
</tr>
</tbody>
</table>

Results are expressed as mean ± SD.

The two-tailed Wilcoxon test was used to assess differences between rest period and training period as well as supine and standing values during tilt test. A probability level < 0.05 was considered statistically significant.

RESULTS

Table 2 shows the results of comparative VO2max values of subjects for the two periods of the test. No significant difference emerged between the two periods.

HR and BP. Values of HR, SBP, DBP, and MBP for the two test periods are given in Table 3. This table shows the response to the tilt test, as well as differences between the rest period (RP) and the intensive training period (ITP).

HR. At rest, there was no significant difference in heart rate between the partial nontraining period and intensive training period. However, there was a significantly less marked response to tilting to the vertical during the intensive training period, with a decrease of 3.8 beats·min⁻¹.

BP. The intensive training period was accompanied by a significant fall in MBP. In contrast, response to tilting in the form of an increase in pressure did not differ between the two periods.

A significant fall in systolic pressure was seen supine and vertical after the intensive training period. There were nevertheless differences in response to tilting between the two periods, with a significant decrease in response at the end of the ITP (P < 0.01). SBP values were significantly higher after tilting during both periods. Differences were also seen in DBP. DBP in the training period was significantly lower supine and vertical. Responses to the tilt test were particularly interesting. Whereas DBP increased during RP, there was a significant decrease in this same pressure during ITP.

HRV. Table 4 provides information on the effects of the tilt test on variability in heart rate and its repercussions on low and high frequency wavebands. Variability is represented by total variance of the HR tracing. It emerged in this study that variability increased on tilting regardless of the period considered. In contrast, change to vertical position after intensive endurance training decreased by 25% (P < 0.05). This intensive training period was also accompanied by smaller variances for supine and tilt, showing that intensive endurance training leads to reduce variability of HR. Study of variations in LF and HF wavebands completed our evaluation of the effects of training.

Low frequencies. Spectral power in the 0.04–0.15 Hz waveband increased significantly after vertical tilting (applying to both periods). However, this response to tilt was 25% less (P < 0.01) during ITP as compared with RP. Spectral power was also less in this frequency range in both positions at the end of ITP.

High frequencies (0.15–0.5 Hz). Analysis of the effects of the tilt test on this range of frequencies showed that spectral power decreased with RP, whereas there was a significant increase in HF after ITP. The training phase was also accompanied by increased vagal control in both positions, with increased spectral power values, supine and with tilt.

LF/HF. The vertical tilt test was accompanied by a marked increase in LF/HF ratio. However, this increase must be viewed cautiously because the value of the ratio was decreased by 44% (P < 0.01) after ITP. Similarly, LF/HF ratio values were significantly lower in both positions after the intensive training phase.

Table 5 shows the various spectral power values for SBP. Total variability in SBP increased differently according to the two periods in the tilt test. The training period was accompanied by a 57% fall in tilt-test response (P < 0.01). Variability in supine SBP was less for ITP than RP, but there was no significant difference.

TABLE 3. Relative rest period and intensive training period values for heart rate (HR), systolic (SBP), diastolic (DBP), and mean (MBP) blood pressure.

<table>
<thead>
<tr>
<th></th>
<th>Decubitus</th>
<th>Standing</th>
<th>Diff (%)</th>
<th>P</th>
<th>Decubitus</th>
<th>Standing</th>
<th>Diff (%)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Intensive Training Period</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>55.8</td>
<td>67.8</td>
<td>+21.5</td>
<td>&lt;0.01</td>
<td>55.5</td>
<td>64*</td>
<td>+15.32††</td>
<td>&lt;0.01</td>
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<tr>
<td></td>
<td>(4.9)</td>
<td>(12.2)</td>
<td></td>
<td></td>
<td>(5)</td>
<td>(12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP (mm Hg)</td>
<td>112.6</td>
<td>128.5</td>
<td>+14.2</td>
<td>&lt;0.05</td>
<td>105.6*</td>
<td>110.2**</td>
<td>+3.47††</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>(9.6)</td>
<td>(8.8)</td>
<td></td>
<td></td>
<td>(8.8)</td>
<td>(9.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBP (mm Hg)</td>
<td>65.3</td>
<td>89.5</td>
<td>+6.4</td>
<td>&lt;0.05</td>
<td>59.2*</td>
<td>57.3**</td>
<td>-3.2††</td>
<td>&lt;0.05</td>
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<tr>
<td></td>
<td>(3.1)</td>
<td>(6.9)</td>
<td></td>
<td></td>
<td>(3.6)</td>
<td>(4.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MBP (mm Hg)</td>
<td>76.5</td>
<td>85.3</td>
<td>+11.5</td>
<td>&lt;0.01</td>
<td>70.3*</td>
<td>78.5*</td>
<td>+11.81††</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>(5.4)</td>
<td>(7.2)</td>
<td></td>
<td></td>
<td>(4.8)</td>
<td>(5.1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results are expressed as mean ± SD.
* Significant differences between periods (P < 0.05).
** Significant differences between periods (P < 0.01).
†† Significant differences between tilt test responses (P < 0.01).
Results are expressed as mean ± SD; nu, normalized unit.
* Significant differences between periods (P < 0.05).
** Significant differences between periods (P < 0.01).
† Significant differences between tilt test responses (P < 0.05).
†† Significant differences between tilt test responses (P < 0.01).

The LF band for SBP showed an 18% decrease in tilt-test response during ITP. Spectral power values were also significantly lower at the end of the training phase.

DISCUSSION

The objective of this study was to demonstrate an autonomic balance change in HR regulation in national level marathon runners after a phase of intense training and a competition. For that purpose, we established a comparison between this intense phase and a period of low-intensity training. A complete 3-wk rest cannot be had in runners of this level. An initial finding showed a relatively low HR (55 beats·min⁻¹). It can be explained by the strong vagal control. This result is consistent with those of previous studies and demonstrates an increase in vagal activity due to endurance training (20,21,28).

The HR values observed in periods of rest and in intense training are not significantly different. This result must certainly be related to the relative stability of the HR, which shows no short-term variation. Furthermore, we believe that given the level, time, and length of athletic participation of the subjects, the resting HR will not vary under a short period of partial detraining. The reason for this is certainly the high level of VO₂max that maintains a low sympathetic activity and a high vagal inhibitory response (7,14).

Conversely, our experimentation demonstrates a significant 5.56% HR reduction in the tilt position in the intense training period. In that position, the HR is more subject to autonomic balance changes. This decrease is directly related to the effects of endurance training on the sympathetic and parasympathetic systems (29,30). This also shows that the HR response to the tilt test is less pronounced during the training period, which denotes a greater influence of the parasympathetic system in the HR’s response. This finding is demonstrated by the spectral analysis, with greater power in high frequencies for the supine and tilt values.

We had a significant increase in LF with passage to the tilt position in both periods, which is in agreement with the literature (4,33,37). However, variations in this frequency band are difficult to interpret because both the sympathetic and parasympathetic systems are influential there.

Our study is distinctive in terms of the results observed in the HF band in tilt position. That part of the HR spectrum reflects vagal activity. The various published studies show a decrease of this frequency range in tilt position. Our results, though, demonstrate a spectral power increase in the 0.15–0.4 Hz band. In addition, they demonstrate a contradictory response in the course of spectral power in the HF band. In the rest period, we have a significant drop in spectral power, which demonstrates a withdrawal of vagal control in orthostatism. This result is in agreement with the studies performed up to now. On the other hand, our study differs in that there is a 31.2% (P < 0.05) increase in spectral power in the HF band at the end of the intense training period.

We could imagine that HF (0.15–0.50 Hz) component change during heavy training is not merely an extension of the normal training response, although this adaptation does not exist with normal training. Moreover, Uusitalo et al. (35) do not find significant change in intrinsic heart rate or cardiac autonomic modulation in female endurance athletes after exhaustive endurance training.

TABLE 4. Effects of tilt test on variance (VAR), relative low-frequency (LF), high-frequency (HF) components values, and the ratio LF/HF of heart rate variability in the subjects during relative rest period and intensive training period.

<table>
<thead>
<tr>
<th></th>
<th>Relative Rest Period</th>
<th>Intensive Training Period</th>
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<tbody>
<tr>
<td></td>
<td>Supine</td>
<td>Standing</td>
</tr>
<tr>
<td>VAR</td>
<td>16.3</td>
<td>34.2</td>
</tr>
<tr>
<td>(8.8)</td>
<td>(13.3)</td>
<td></td>
</tr>
<tr>
<td>LF norm (nu)</td>
<td>1.7</td>
<td>3.7</td>
</tr>
<tr>
<td>(0.5)</td>
<td>(3.6)</td>
<td></td>
</tr>
<tr>
<td>HF norm (nu)</td>
<td>1.1</td>
<td>0.65</td>
</tr>
<tr>
<td>(0.9)</td>
<td>(0.8)</td>
<td></td>
</tr>
<tr>
<td>LF/HF</td>
<td>1.5</td>
<td>8.6</td>
</tr>
<tr>
<td>(1.7)</td>
<td>(5.4)</td>
<td></td>
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</tbody>
</table>

TABLE 5. Effect of tilt test on absolute values in variance (VAR) and low-frequency (LF) components of systolic blood pressure variability in the subjects between relative rest period and the intensive training period.

<table>
<thead>
<tr>
<th></th>
<th>Relative Rest Period</th>
<th>Intensive Training Period</th>
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<tbody>
<tr>
<td></td>
<td>Supine</td>
<td>Standing</td>
</tr>
<tr>
<td>VAR</td>
<td>23.69</td>
<td>39.21</td>
</tr>
<tr>
<td>(2.3)</td>
<td>(3.2)</td>
<td></td>
</tr>
<tr>
<td>LF (0.04–0.15 Hz)</td>
<td>1.43</td>
<td>2.21</td>
</tr>
<tr>
<td>(0.32)</td>
<td>(0.57)</td>
<td></td>
</tr>
</tbody>
</table>

Results are expressed as mean ± SD.
* Significant differences between periods (P < 0.05).
** Significant differences between periods (P < 0.01).
† Significant differences between tilt test responses (P < 0.05).
†† Significant differences between tilt test responses (P < 0.01).
Vasovagal syncope refers to vasodilatation and inappropriate bradycardia leading to hypotension and loss of consciousness (8). It is generally believed that the vasodilatation is a passive process mediated by sympathetic withdrawal, whereas the bradycardia is active, secondary to increase parasympathetic cardiac activity. But in our case, we have not a decrease of sympathetic tone but an important increase in vagal tone. Thus, we hypothesized that autonomic balance control could be disturbed with a more vagal predominance with fatigue due to heavy endurance training.

Next, we believe that the explanation for the high parasympathetic activity lies in the high level of fatigue of our subjects who had just undergone 12 wk of intense training, followed by a marathon or half-marathon competition. This state of fatigue was experienced through a lowered orthostatic tolerance with signs of pallor, sudation, and blackouts that began to appear. We could compare these results with patients being evaluated clinically for neurocardiogenic syncope. A reduction of heart rate variability with a strong vagal activity has been reported in several cardiological and no cardiological diseases (4,15,22,23). These results could confirm the vagal origin of syncope among healthy young adults (36).

Our experimentation also allowed us to observe the behavior of sympathetic activity represented by the LF/HF ratio. Total HR variance can evaluate R-R interval variability. Previous studies (3,9) have shown an increase in HR variability with endurance training. This rise is attributed to increased tidal volumes and changes in the intrinsic physiologic qualities of cardiac muscle. This sympathetic system stimulation takes place through baroreceptors and volume receptors (17).

Our study demonstrates a significant decrease in total variance in the intense training phase in comparison with the detraining phase in the two situations, supine and tilt. The hypothesis for this decrease could be related to an advanced state of fatigue of the runners who underwent 12 wk of intense training accentuated by a marathon or half-marathon competition. This condition could be placed along the continuum of fatigue. The overreaching phase may be characterized by parasympathetic hypertonia (16). This type of fatigue could be sometimes combined with a reduced resting HR, a reduced maximal HR, and slower postexercise recovery. In some cases, marked limitation of the effort HR is observed. This condition had already been noted in athletes displaying significant underperformance (personal communication). Nevertheless, we cannot state that our subjects suffer from overtraining because parameters, such as catecholamines and steroid hormones, were not recorded. Similarly, we cannot attest to the presence of markers described by Fry et al. (13).

This result and the data from the literature suggest that spectral analysis could be used as a means of early detection of fatigue because autonomic balance would be one of the first to be affected in case of fatigue-induced homeostatic disturbance. If so, we would have a suitable tool to search for premonitory signs of fatigue. Our study also demonstrated a reduction in mean and systolic blood pressures. The hypothetical mechanisms that would likely explain a resting blood pressure drop in endurance-trained subjects are unclear.

To understand the decrease in the mean blood pressure, we have to consider central and peripheral mechanisms that modify the cardiac output and total peripheral resistance (TPR). Studies have shown that the resting cardiac output in trained athletes may be increased, modified, or reduced. However, in this last case, the reduction in cardiac output did not correlate with lowered blood pressure (24). The blood pressure reduction could also be the result of a change in baroreceptor activity. In fact, a reduction in baroreflex sensitivity has been shown in endurance-trained subjects under increased carotid pressure (neck suction) (28) or decreased pressure in the lower part of the body (18). Changes in peripheral resistance play an important role in establishing the blood pressure conditions in athletes. Other factors such as reduced vasomotor tone and its control by sympathetic activity could be evoked to account for the lowered BP.

This decrease in sympathetic activity is shown by spectral analysis of the systolic pressure in the low frequencies. The spectral power values are significantly lower in the supine and tilt positions in the intense training phase. We also have an 18% ($P < 0.05$) spectral power decrease in tilt, which would denote a reduction in sympathetic vasomotor tone. Similary, the reduction in vasomotor tone can be considered through a study of the diastolic blood pressure. On the one hand, our study demonstrates lower DBP values in the training period in the supine position, and on the other hand, it shows that the tilt-test response differs in the two periods. The DBP increases in the upright position in RRP, whereas it decreases by 3.2% ($P < 0.05$) in ITP. This decrease is certainly due to a reduction in peripheral resistance caused by training fatigue.

This study shows that spectral analysis of the heart rate appears to be a suitable model to study the effects of endurance training on cardiovascular reactivity. Furthermore, it would seem that the course of the autonomic balance is a good index for early detection of fatigue before the other physiologic parameters are disturbed. Henceforth, it would be interesting to see whether such changes occur after intense training in predominantly anaerobic activities, and to possibly detect occurrences at the beginning of hard fatigue.

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