Otto F. Barak\textsuperscript{1}, Oleg S. Glazachev\textsuperscript{3}, Helena N. Dudnik\textsuperscript{2}, Irina I. Korobeinikova\textsuperscript{2}, Aleksandar V. Klašnja\textsuperscript{1}, Nikola G. Grujić\textsuperscript{1}

\textsuperscript{1} Department of Physiology, Medical Faculty, University of Novi Sad, Hajduk Veljkova 3, 21000 Novi Sad, Serbia
\textsuperscript{2} P. K. Anokhin Research Institute of Normal Physiology, Russian Academy of Medical Sciences
\textsuperscript{3} I. M. Sechenov Moscow Medical Academy, Moscow, Russia

PECCULARITIES OF THE AUTONOMIC BALANCE ASSESSED THROUGH HEART RATE VARIABILITY ANALYSIS IN SPORTSMEN AND NONSPORTSMEN

ABSTRACT: A comparative study was used to analyze the difference in autonomic balance assessed by time and frequency domain parameters of heart rate variability (HRV) between students — athletes and non-sportsmen. Five-minute digital ECG trays were recorded in 21 students — athletes, 10 basketball players recruited from first league clubs of Novi Sad and the Serbian representatives and 11 rowers from the Novi Sad rowing club “Danubius”. The control group was formed by 15 non-sportsmen, students of the Medical faculty in Novi Sad who underwent the same registrations. Time and frequency-domain of HRV were analyzed by a software developed by the company “Neurosoft”, VNS-Spektr, Ivanovo, Russia. Resting heart rate in athletes was significantly lower (p < 0.01) than in non-sportsmen. In time-domain parameters HRV significantly higher values were present in the group of sportsmen as opposed to non-sportsmen — RRNN (p < 0.01), RMSSD (p < 0.02) and pNN50 (p < 0.01). In frequency-domain of HRV statistically significant difference between the two groups was observed only in normalized values of LF and HF (p < 0.05) and their ratio LF/HF (p < 0.02). LF\textsubscript{n} was larger in non-sportsmen than in students-athletes. On the other hand HF\textsubscript{n} was larger in athletes than in non-sportsmen. The LF/HF ratio was larger in non-sportsmen (2.87 ± 0.34) than in athletes (1.91 ± 0.20). After dividing the athletes recruited for this investigation into two groups (basketball players and rowers) significant level of difference (p < 0.05) in HRV data was present only in the VLF spectrum (2060.55 ± 290.68 ms\textsuperscript{2} for rowers and 1303.30 ± 169.95 ms\textsuperscript{2} for basketball players).

KEY WORDS: Heart rate variability, sportsmen

INTRODUCTION

The regular practice of physical exercise is an important factor to reduce morbidity and mortality rates of cardiovascular and all other conditions. Even though moderate exercises enhance health conditions, there are recent and con-
sistent evidences that high intensity or strenuous exercises have even more significant positive effect reducing up to two times mortality rates over a decade (Tanasescu, Leitzmann, Rimm, 2002).

Monitoring heart rate (HR) has been used to evaluate responses to different exercise stressors for a long time (Sudakov, Yumakov, Tarakanov, 1995). Recently, the attention has shifted slightly towards the field of heart rate variability (HRV). Even when HR is relatively stable, the time between two beats (R-R) can differ substantially (Achten, Jeukendrup, 2003). The variation in time between beats is being defined as HRV, and currently represents the most promising quantitative marker of autonomic activity (Task Force, 1996, Tulppo, Huikuri, 2004).

HRV is assessed by examining the beat-to-beat variations in normal R-R intervals. Originally, HRV was quantified in time-domain, i.e., R-R intervals in milliseconds (ms) plotted against time. The standard deviation of R-R intervals (SDNN), that is the square root of variance, can show short-term as well as long-term R-R interval variations. Differences between successive R-R intervals provide an index of cardiac vagal control. This can be quantified by calculating the root mean square successive difference (RMSSD) of all R-R intervals and the number of adjacent R-R intervals differing more than 50 ms expressed as a percentage of all intervals over the collection period (pNN50) (Achten, Jeukendrup, 2003).

In contrast to time-domain measures of HRV, recent developments in microprocessor technology have enabled the calculation of frequency measures based on mathematical manipulations performed on the same ECG-derived data. Instead of plotting the HRV as the change in R-R intervals over time, it is plotted as the frequency at which the length of the R-R interval changes. The main parameters on the frequency domain are very low frequency power (VLF) > 0.4 Hz, low frequency power (LF) 0.04—0.15 Hz, high frequency power (HF) 0.15—0.4 Hz, ratio between LF and HF (LF/HF) and total power (TP). HF and LF can also be expressed in normalized units, which represent the relative value of each power component in proportion to TP minus the VLF component (Achten J., Jeukendrup A. E., 2003). Some authors report even on the existence and interpretation of ultra-low frequency power (ULF) (Task Force, 1996, Tulppo, Huikuri, 2004).

Although cardiac automaticity is intrinsic to various pacemaker tissues, heart rate and rhythm are largely under the influence of the autonomic nervous system and of various hormones. The peaks at different frequencies reflect the different influences of the parasympathetic and sympathetic nervous system (Pomeranz, Macaulay, Caudill et al., 1985), involvement of some humoral mechanisms in regulation of cardiovascular functions (Kotelnikov, Nozdramev, Odinak, 2002).

Part of the HRV is caused by respiratory sinus arrhythmia. Many studies support the view that respiratory sinus arrhythmia is generated by central coupling of the respiratory oscillator with autonomic centers in the brain stem. However a mechanical cardiopulmonary coupling has also been suggested (Mc Craty, Watkins, A., 1996, Tulppo, Huikuri, 2004). It has been shown in both clinical and experimental settings that parasympathetic
activity is a major contributor to the HF component of the HRV power spectrum (Tanaescu, Leitzmann, Rimm, 2002).

The evidence for the interpretation of the LF component is much more controversial. The LF is seen as a marker of sympathetic modulation by some authors, while others suggest it is a parameter that includes both sympathetic and parasympathetic influences. It was being ascribed to sympathetic modulation of cardiac pacemaker activity, because a variety of studies demonstrated that acute interventions that increase sympathetic nervous system activity, such as orthostatic perturbations, mental stress, handgrip exercise increase LF spectral power of the HR (Kotelnikov, Nozdrachev, Odinak, 2002).

It has been suggested that thermoregulation affects VLF heart rate variability. Studies indicate that both direct effects of temperature on pacemaker activity of the sinus node and indirect effects mediated via autonomic nervous system evoke temperature effects on HR and HRV. For not being completely attributed to any specific physiological mechanism the interpretation of VLF remains a subject of debate. The major constituent of this component is thought to be non-harmonic or fractal in nature thus assessed from short-term recordings it is a dubious measure (McCraty, Watkins, 1996).

The ratio of LF to HF is considered to reflect the sympatho-vagal balance (Tanaescu, Leitzmann, Rimm, 2002). This concept has been promoted by some researchers, but it lacks a physiological base. Although sympathetic and parasympathetic nervous activity constantly interacts there is no fundamental evidence that they are balanced.

The goal of our study is to reveal the differences in resting autonomic balance and in autonomic reactivity to the incremental physical load assessed by time and frequency domain parameters of heart rate variability (HRV) between students — sportsmen and non-sportsmen. In the current paper we have described only the intra-group differences in autonomic tone at the state of rest.

DESIGN OF THE STUDY AND METHODS

Subjects. All the measurements were carried out on 21 students — athletes, 10 basketball players recruited from first league clubs of Novi Sad and the Serbian representatives (age 18.7 ± 0.26 yrs, height 197 ± 2.27 cm, weight 88.9 ± 3.62 kg, active for 5.6 ± 0.4 yrs) and 11 rowers from the Novi Sad rowing club Danubius (age 16 ± 0.36 yrs, height 181.82 ± 2.38 cm, weight 72.46 ± 2.86 kg, active for 4.27 ± 0.24 yrs). The control group was formed of 15 non-sportsmen, students of the Medical faculty in Novi Sad, who had no regular physical activity (more than 3 times a week, longer than 1 hour daily) during the last six months prior the measurements. All the participants underwent a general physical examination to exclude eventual acute diseases and ailments of the cardio-respiratory and locomotor system.

Protocol. A 5-minute digital ECG was recorded in a comfortable sitting position (VNS-Spektr, Neurosoft, Ivanovo, Russia). The epoch gained from the I lead was saved in a computer for further analysis. All R-R intervals were edited by visual inspection to exclude all the undesirable beats. Time-
SDNN, RMSSD, pNN50) and frequency-domain analysis (after fast Fourier transformation) (TP, VLF, LF, HF, LFn, HFν, LF/HF, %VLF, %LF, %HF) was obtained after computer analysis of the digital electrophysiological signals.

The numerical data were statistically processed with the Statistica for Windows 6.0 software package. Parametric statistic was applied to calculate standard statistical factors (mean, standard deviation, error of the mean, etc.). Student t test was used to perform intra-group comparison. Statistical significance of difference was established by one-way ANOVA.

RESULTS

In this investigation we analyzed the time- and frequency-domain parameters of HRV in athletes and sedentary non-sportsmen. The results of each group are presented in table 1 (as the mean value and standard error).

Resting heart rate in athletes (68.00 ± 1.87 min⁻¹) was significantly lower (p < 0.01) than in nonsportsmen (79.54 ± 2.15 min⁻¹). In time-domain parameters of HRV significantly higher values were present in the group of athletes as opposed to non-sportsmen: RRNN were 896.76 ± 124.93 ms and 761.15 ± 119.93 ms respectively (p < 0.01), RMSSD were 48.14 ± 13.44 ms and 35.15 ± 13.78 ms respectively (p < 0.02) and pNN50 were 26.09 ± 2.86 and 14.17 ± 3.14 respectively (p < 0.01).

<table>
<thead>
<tr>
<th>№</th>
<th>Parameters</th>
<th>Sportsmen</th>
<th>Non-sportsmen</th>
<th>Dif. signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Pulse (min⁻¹)</td>
<td>68.00 ± 1.87</td>
<td>79.54 ± 12.15</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>2.</td>
<td>RRNN (ms)</td>
<td>896.76 ± 124.93</td>
<td>761.15 ± 119.93</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>3.</td>
<td>SDNN (ms)</td>
<td>61.10 ± 13.19</td>
<td>59.77 ± 14.99</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>4.</td>
<td>RMSSD (ms)</td>
<td>48.14 ± 13.44</td>
<td>35.15 ± 13.78</td>
<td>p &lt; 0.02</td>
</tr>
<tr>
<td>5.</td>
<td>pNN50 (%)</td>
<td>26.09 ± 12.86</td>
<td>14.17 ± 3.14</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>6.</td>
<td>CV (%)</td>
<td>6.90 ± 10.37</td>
<td>7.81 ± 10.53</td>
<td>p &gt; 0.05</td>
</tr>
</tbody>
</table>

Frequency-domain parameters:

<table>
<thead>
<tr>
<th>№</th>
<th>Parameters</th>
<th>Sportsmen</th>
<th>Non-sportsmen</th>
<th>Dif. signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>TP (ms²)</td>
<td>4265.67 ± 449.13</td>
<td>4827.92 ± 757.37</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>8.</td>
<td>VLF (ms²)</td>
<td>1699.95 ± 188.34</td>
<td>2275.31 ± 537.14</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>9.</td>
<td>LF (ms²)</td>
<td>1605.67 ± 222.34</td>
<td>1781.00 ± 254.40</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>10.</td>
<td>HF (ms²)</td>
<td>960.19 ± 152.25</td>
<td>771.62 ± 185.72</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>11.</td>
<td>LFn (nu)</td>
<td>62.61 ± 2.37</td>
<td>71.08 ± 2.84</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>12.</td>
<td>HFν (nu)</td>
<td>37.39 ± 2.37</td>
<td>28.92 ± 2.84</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>13.</td>
<td>LF/HF</td>
<td>1.91 ± 0.20</td>
<td>2.87 ± 0.34</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>14.</td>
<td>%VLF (%)</td>
<td>41.47 ± 3.07</td>
<td>43.12 ± 5.45</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>15.</td>
<td>%LF (%)</td>
<td>36.89 ± 2.57</td>
<td>40.68 ± 4.45</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>16.</td>
<td>%HF (%)</td>
<td>21.62 ± 1.70</td>
<td>16.19 ± 2.42</td>
<td>p &gt; 0.05</td>
</tr>
</tbody>
</table>
**Resting time- and frequency-domain parameters of HRV in students — athletes and non-sportsmen (M ± SE)**

In frequency-domain of HRV statistically significant difference between the two groups was observed only in normalized values of LF and HF (p < 0.05) and their ratio LF/HF (p < 0.02). LFn was larger in non-sportsmen (71.08 ± 2.84) than in athletes (62.61 ± 2.37). On the other hand HFn was larger in athletes (37.39 ± 2.37) than in non-sportsmen (28.92 ± 2.84). The LF/HF ratio was larger in non-sportsmen (2.87 ± 0.34) than in athletes (1.91 ± 0.20).

After dividing the athletes recruited for this investigation into two groups (basketball players and rowers) we analyzed the differences between them. As expected, basketball players were significantly taller and weigh more than rowers (p < 0.01). Significant level of difference (p < 0.05) in HRV data was present only in the VLF spectrum (2060.55 ± 290.68 ms² for rowers and 1303.30 ± 169.95 ms² for basketball players). No correlation was found among the parameters of the two sub-groups.

**DISCUSSION**

In light of a large number of scientific data one can not deny that aerobic exercise leads to improvement in the maximal oxygen uptake, due to at least in part, an increase of cardiac output from an increase in systolic volume (Carter, Banister, Blaber, 2003). The volume load during endurance training results in adaptive changes in many aspects of cardiovascular function. The heart improves its ability to pump blood, mainly by increasing stroke volume, which occurs because of an increase in end-diastolic volume and a small increase in left ventricular mass. In contrast, strength training results in larger increase in left ventricular mass and little or no change in ventricular volume. Endurance exercise also decreases the metabolic load on the heart at rest and at any submaximal exercise intensity — by increasing stroke volume and decreasing heart rate (Almeida, Araújo, 2003).

Long-term physical training influences cardiac rhythm. Maximal HR does not tend to change, whereas sinus bradycardia is seen in resting conditions and a slower increase in heart rate at any degree of submaximal oxygen uptake. These changes are probably related to mechanisms such as increase of venous return and systolic volume, improved myocardial contractility (Carter, Banister, Blaber, 2003). Adjustments of HR behavior from aerobic training may also be due to changes of sympathetic-vagal balance — higher parasympathetic and lower sympathetic activity — shown in many studies (Carter, Banister, Blaber, 2003).

Enhanced vagal tone to the sinus node has also been proposed to play a role in sinus bradycardia. Cardiac autonomic blockade study of humans has reported an increase in parasympathetic control of heart rate following endurance training of proper duration and intensity. Parallel to a large increase in VO₂ after endurance training, an increase in parasympathetic control of HR was shown (Pomeranz, Macaulay, Caudill, 1985). Still it remains un-
clear if the improvement of the aerobic condition from training enhances cardiac vagal tone, thus resting HR variability (Almeida, Araujo, 2003).

When looking at the time-domain variables of HRV, in most studies trained individuals had significantly higher R-R interval times, SDNN, pNN50 and RMSSD compared with their age- and weight-matched sedentary controls (Carter, Banister, Blaber). RMSDD reflects the short-term variance in HR and is the primary time-domain measure used to estimate the high-frequency beat-to-beat variations providing an estimate of the parasympathetic regulation of the heart. Increased values in athletes like in our case would indicate a parasympathetic predominance.

Whether the sympathetic nervous system also contributes to the lower resting HR is still controversial (Tanasescu, Leitzmann, Rim, 2002). Endurance training seems to reduce the efferent sympathetic neural outflow to the sinoatrial node in the heart (Aubert, Seps, Beckers, 2003). Possible mechanisms for such a decrease in a trained individual is that the reflex heart rate response to myocardial stretch may be augmented through central, peripheral and reflex adaptations to endurance training (Tulppo, Hautala, Makikallio, 2003).

Recent studies offer a different explanation revealing intrinsic electrophysiological adaptations, such as changes in the sinus node automaticity and atrioventricular node conductivity (Smith, Hudson, Graitzer et al., 1989). Athletic training might induce intrinsic adaptations in the conduction system (mostly influencing conduction velocity), which could contribute to the higher prevalence of conductive tissue abnormalities observed in athletes (Smith, Hudson, Graitzer et al., 1989). Such indices were also present in our study. Four of the sportsmen presented VES in rest and two of them were diagnosed earlier with left branch block. A possible hypothesis as to the controversy about autonomic versus non-autonomic determinants of electrophysiological adaptations in athletes could be a fundamental difference between short- and long-term physical training programs. Short-term trainings could induce autonomic adaptations, with a reduction of sympathetic activity and an increase in parasympathetic activity (leading to bradycardia). On the other hand, long-term aerobic training, eliciting atrial and ventricular dilatation, would induce intrinsic electrophysiological adaptations and enhance parasympathetic activity (Shi, Stevens, Foresman et al., 1995).

When the data are interpreted using frequency domain variables, the results are slightly less consistent. While some investigators report TP, HF and LF (in absolute values) significantly higher in athletes compared with sedentary individuals, others reveal no such changes (Stein, Moraes, Cavalcanti et al., 2000). In our investigation changes appeared only in the normalized values of HF and LF. The HF expressed in normalized units was significantly higher in trained individuals in most of the studies. On the other hand the trained individuals in the study of E. L. Melanson and P. S. Freeisson (2001) had significantly lower LF compared with their sedentary counterparts.

In our investigation athletes were characterized with lower LF/HF ratio. The ratio of LF to HF is considered to reflect the sympatho-vagal balance. Ac-
According to this view higher values suggest a sympathetic predominance and lower parasympathetic predominance. This concept has been promoted by some researchers, but it lacks a physiological base. However it is true that both sympathetic and parasympathetic motoneurons respond to interrelated neural influences. It should therefore be noted that the LF and HF components of HRV provide a measure of the degree of autonomic fluctuation rather than a level of autonomic tone (McCraty, Watkins, 1995).

Different values of VLF power spectrum between the groups of basketball players and rowers could be explained by their metabolic and hormonal adaptations to different training regimes. Alongside temperature, endocrine factors like reproductive hormones, steroids, renin-angiotensin system also affect the VLF component of HRV (Kotelnikov, Nozdrachev, Odinak, 2002). Training regimes tend to evoke hormonal changes that will eventually result in a morpho-physiological adaptation to the presented training stimulus. Another difference between the sportsmen of these two groups is age. The rowers are significantly younger than basketball players being in the hormonally active and fluctuant period of their adolescent lives.

Longitudinal studies reveal that moderate to vigorous intensity endurance training program in adult, previously sedentary men increased markers of parasympathetic activity (significant increase in HF power) after 12 weeks (Lomala, Huikuri, Oja et al., 2000). Others find no consistent changes in HRV, although a significant reduction of HR is observed. These authors blame the short duration of the training program and suggest that in order to obtain any effect on HRV the training program should last for a period of at least a year (Stein, Moraes, Cavalcanti et al., 2000).

Although it would be easy to conclude from the above mentioned studies that training increases HRV, studies are needed to investigate the direct effects of training on indices of HRV. While most cross-sectional studies show that endurance-trained athletes have higher HRV than their age- and weight-matched controls, the results from longitudinal studies are less conclusive. The data suggest that the duration of the exercise program might be an important factor when looking at the effects of exercise training on HRV. On the other hand vigorous training programs are necessary to induce changes in HRV, so in addition to exercise duration, exercise intensity and training volume may also play a role, yet no clear guidelines exist for the optimal training stimulus to obtain solid training adaptations (Shi, Stevens, Foresman et al., 1995).

In general, obtained data allows us to conclude that long-term (several years) adaptation to regular training programs in students — sportsmen comparing to non-sportsmen controls at the state of rest is reflected in the increase of parasympathetic activity, slight decrease in sympathetic mechanisms and in shifting of the autonomic balance to vagal predominance.

The provided research was done on the base of the agreement on scientific cooperation between the Medical Faculty of the University of Novi Sad (Novi Sad, Serbia), P. K. Anokhin Research Institute of Normal Physiology, Russian Academy of Medical Sciences and I. M. Sechenov Moscow medical academy (Moscow, Russia). This investigation was supported by Provincial Secretariat for Science and Technological Development of Vovodina N°: 114-451-01395/2006-02.
REFERENCES


24
ПОСЕБНОСТИ АУТОНОМНЕ КОНТРОЛДЕ ДОБИЈЕНЕ КРОЗ АНАЛИЗУ ВАРИЈАБИЛНОСТИ СРЧАНЕ ФРЕКВЕНЦЕ КОД СПОРТИСТА И НЕСПОРТИСТА

Ото Ф. Барак1, Олег С. Глазачев3, Хелена Н. Дудник2, Ирина И. Коробеиникова2, Александар В. Клашић1, Никола Г. Грујић1

1 Завод за физиологију, Медицински факултет, Универзитет у Новом Саду, Нови Сад, Хајдук Вељкова 3, 21000 Нови Сад, Србија
2 П. К. Анокхин Истраживачки Институт Нормалне физиологије, Руска академија медицинских наука
3 И. М. Сеченов Московска Медицинска Академија, Москва, Русија

Резиме

Циљ истраживања била је компаративна анализа варијабилности срчане фреквенције (Heart Rate Variability — HRV) код спортиста и неспортиста. Спроведена су регистровања ЕКГ-криве у трајању од 5 минута код 21 спортисте, и то 10 првоглавића кошаркаша који играју у новосадским клубовима и репрезентатива, односно 11 веслаца из веслачког клуба “Данубиус” из Новог Сада. Контролну групу представља је 15 неспортиста, студената Медицинског факултета у Новом Саду. Добијени временски и фреквенцијски параметри HRV-а су анализирани помоћу софтвера Нeuрософт, ВНС-Спектр, који су развили руски научници из Иванова, Руска федерација. Вредности HRV-а у миру у биле значајно ниже код спортиста (p < 0.01) у односу на вредности код неспортиста. Код анализе временских параметара вредности HRV-а су биле сигнфикантно више код спортиста у односу на неспортиста — RRNN (p < 0.01), RMSSD (p < 0.02) и pNN50 (p < 0.01). У погледу фреквенцијских параметара, статистички значајна разлика је била уочивана у пико и нормираних вредности више (HFn) и ниже фреквентне области (LFn) (p < 0.05) и односа LF/HF (p < 0.02). Вредност LFn биле су више код неспортиста у односу на спортисте. С друге стране, вредности HFn биле су више код спортиста. Однос LF/HF је показивао више вредности код неспортиста (2.87 ± 0.34), него код спортиста (1.91 ± 0.20). Међусобним упоређивањем у групи спортиста, статистички значајна разлика (p < 0.05) код вредности HRV-а постојала је само у домену веома ниске фреквенције (VLF) (2060.55 ± 290.68 ms² код веслача и 1303.30 ± 169.95 ms² код кошаркаша).