Original article

Long-term exercise training improves autonomic nervous system profile in professional runners

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Abstract

Introduction: Moderate-intensity endurance training causes increased parasympathetic activity while very intensive (extreme) exercise loads may lead to persistently elevated sympathetic tone in champion class athletes preparing for competitions. Exercise training loads used by regional class sportsmen are usually somewhat less intensive.

Aim: To assess the changes in autonomic nervous system activity in a group of regional class runners during a long-term training cycle preparing them for competitions.

Methods: Twenty-four regional class runners (including 22 males) with a mean age of 24±4 years (18 to 34 years) were enrolled in the study. Resting heart rate (mean HR) and autonomic system tone were assessed in the final period of the preparatory training (1) and in the terminal phase of the competition period (2). Additionally, ten-minute long continuous non-invasive acquisitions of systolic arterial blood pressure – SAP (*Finapress*, *Ohmeda*) and heart rate period – HP (*Mingograf 72°C*) were carried out in each subject. Then arterial baroreflex sensitivity by means of spectral analysis (BRS_WBA) and indices of heart rate variability (SDNN, pNN50, RMSSD, TP, LF, LFnu, HF, LF/HF) were calculated from the recorded SAP and HP signals.

Results: A statistically significant increase in indices of heart rate variability such as BRS_WBA, SDNN, pNN50, TP and LF in period 2 when compared with period 1 was found. Their values were 17.2±8.2 *vs* 11.5±5.1 ms/mmHg (p=0.0001), 91±55 *vs* 70±36 ms (p=0.0002), 48±24 *vs* 38±23% (p=0.03), 4364±2614 *vs* 3384±2298 ms^2 (p=0.01), 2262±2031 *vs* 1398±1203 ms^2 (p=0.002), respectively. Borderline elevation of the RMSSD index (83±62 and 67±37 ms respectively for period 1 and period 2; p=0.09) was also noted. The other calculated parameters did not differ significantly.

Conclusions: Long-term intensive exercise training, employed by regional class runners preparing for competitions, changes the autonomic profile, promoting parasympathetic dominance. This may be an important argument to encourage many young and healthy people to engage in endurance sports at such intensity.

Key words: arterial baroreflex sensitivity, heart rate variability, physical training

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Introduction

The human body reacts to physical exercise initially by decreasing vagal tone, which is followed by sympathetic activation of the autonomic nervous system (ANS). Exercise cessation leads to a rapid return of the parasympathetic system to the resting tone. This pattern follows either single or long-term training load. Raczak et al. showed that even a single, low-intensity instance of exercise in sedentary subjects improved arterial baroreflex sensitivity (BRS) and SDNN index of short-term heart rate variability (HRV) [1]. Cook et al. observed similar changes following four-week endurance training [2]. Similar results have been reported by other authors [3-7], who observed not only ANS tone changes but also

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normalisation of arterial blood pressure, heart rate and improvement of exercise capacity [2, 8-10].

However, it is known that very intensive exercise loads may lead to a negative persistent shift in the ANS from parasympathetic toward sympathetic predominance. For example, Iellamo et al. noted that increasing training loads from 75% to 100% of the maximum allowed in rowers preparing for the World Championship led to elevation of short-term LFnu and LF/HF HRV indices and a decrease in HFnu and BRS, the typical pattern of increased adrenergic tone [11]. Bernardi et al. demonstrated that even a single instance of very intensive exercise, such as a marathon, led to increased adrenergic tone persisting for many hours after exercise cessation [12]. Other data indicate the maintenance of sympathetic activation up to two days following the end of the marathon race [13]. The prolonged elevated adrenergic tone following extremely strenuous physical exercise must be considered as the overtraining syndrome that is currently a subject of interest of many investigators [14-18].

Until recently most studies regarding the effects of long-term exercise training were focused on champion class athletes. There is a shortage of data on less intensive training loads in regional class sportsmen. Differences between the aforementioned groups seem to be significant because of different exercise intensity and its magnitude. Moreover, the groups of world class athletes consist of a small number of subjects who are monitored very carefully during their exercise. On the contrary, the groups of regional class sportsmen are much more numerous and so it is more difficult to provide them with such strict control.

Aim

To estimate the changes in ANS activity in a group of regional class runners after a long-term training cycle preparing them for competitions.

Methods

The study involved young athletes of endurance sports (medium- and long-distance runners).

Study inclusion criteria:

1. professional sport engagement for at least 2 years;
2. negative medical history, especially of cardiovascular disease;
3. no drugs or other addictive substances (tobacco and alcohol) used;
4. normal heart rhythm in resting ECG;
5. athlete's informed consent to participate in the study.

The training programme of the study involving sportsmen preparing for competitions consisted of:

- **training of a preparatory period** of 4 months and with large magnitude exercises aimed at building aerobic endurance (2-hour training sessions, 5 to 6 times a week, predominance of aerobic exercises – up to 90% of the total load);
- **training of a starting period** of 4 to 5 months and with a lower magnitude of training loads, but performed with much higher intensity and mixed (aerobic-anaerobic) or anaerobic exercises. The number of training units was equal to the preparatory training but because of the higher intensity in the starting period the duration of a training unit in the latter one was shorter. The period of starting training consisted of two subperiods: **the subperiod of form stabilisation** (direct preparation for competition 5 to 8 months) and the **starting period**. The starting period in competition aimed to maintain high starting disposition by means of training of high intensity and lower magnitude and employment of particular exercises enabling maintenance of high performance.

Examinations planned in the study protocol were carried out twice in each subject: first in the final period of the preparatory training and then during the starting period. Standard laboratory conditions for autonomic reactivity studies were utilised. After a 15-minute resting period in the supine horizontal position necessary for circulatory system stabilisation, 10-minute acquisition of systolic arterial pressure (SAP) and heart rate period (HP) signals were obtained, followed by an analysis of BRS and HRV.

A laboratory test enabling calculation of maximum oxygen consumption (VO_2max) was performed to evaluate oxygen efficiency.

Assessment of autonomic reactivity

Continuous non-invasive measurement of systolic arterial pressure was performed using FINAPRES (Ohmeda) with the pressure cuff placed on the middle phalanx of the middle right finger and heart rate using the MINGOGRAF 720C device. The *self-adjustment* function of FINAPRES was switched on directly before the acquisition and then again after completion of each acquisition in order to recalibrate the device.

Analogue signals of SAP and HP recorded during acquisitions were transformed and synchronised by means of an analogue-digital converter with a sampling rate of 250 Hz and transferred to a computer equipped with POLYAN software [19] that enabled calculations of specific BRS and HRV indices. A HP signal resolution of

1 msec was achieved employing a linear interpolation algorithm.

First during the BRS analysis all extrasystolic beats and trends were removed from the records. Then, a fragment of stationary SAP and HP records of at least 240 seconds was selected for further analysis. Arterial baroreflex sensitivity was automatically assessed, which limited study subjectivity. The BRS_WBA index was calculated from the spectral analysis of spontaneous SAP and HP variability by means of the Blackman-Tukey algorithm utilising Parzen's window 0.03 Hz wide as a mean value of transfer function (TF) module within the frequency range of 0.04-0.15 Hz including all points of SAP and HP curves irrespectively of their magnitude or coherence variability. The result of BRS was expressed in milliseconds per mmHg (ms/mmHg).

In the short-term HRV study the following parameters were assessed [20]:
- SDNN – standard deviation of all R-R intervals of the sinus rhythm [ms];
- pNN50 – the number of pairs of adjacent R-R intervals differing by more than 50 ms in the entire recording divided by the total number of all R-R intervals [%];
- RMSSD – nocturnal root mean square successive difference [ms];
- TP – total power spectrum [ms^2];
- LF – spectrum power in low frequency band 0.04-0.15 Hz [ms^2];
- HF – spectrum power in high frequency band 0.15-0.4 Hz [ms^2];
- LFnu – relative power density of low frequency component expressed as normalised units (NU);
- LF/ HF-LF to HF ratio.

Aerobic efficiency examination

A laboratory test enabling calculation of maximum oxygen consumption (VO_2 max – *oxygen threshold*) was performed to evaluate oxygen efficiency. Expiratory air direct analysis was performed using the *EOS Sprint* measuring system manufactured by Jeager company. Expiratory gas analysis at rest was carried out first in the cardio-pulmonary test to assess the resting metabolism. After acquisition of the rest parameters, the exercise test on a cycle ergometer was started. During the first 5 minutes of the study, a load of 1.5 W/kg was used, then the exercise load was systematically increased by 25 W per minute up to the moment the examined subject discontinued exercise due to complete exhaustion. Standard indices of expiratory air such as oxygen extraction (VO_2) and carbon dioxide expiration (VCO_2) were continuously analysed during resting, exercise and post-exercise phases of the study. Heart rate period was monitored using ECG countershaft. Then, VO_2max expressed as ml/kg/min was calculated during the exercise. The aerobic efficiency examination was carried out in the Physiology Department of the Academy of Physical Education and Sport in Gdańsk.

This study was performed as part of a more extensive programme assessing the influence of exercise on autonomic nervous system activity. The programme received the permission of the Independent Ethical Committee for Scientific Studies of the Medical University of Gdańsk (NKEBN/10/2003).

Statistical analysis

Statistical analysis was performed using the Statistica 6.0 software package. A comparison of particular parameters during preparatory and starting training was assessed with Wilcoxon signed ranks test. All data are expressed as mean value ± standard deviation. A value of *P* less than 0.05 was considered significant.

Results

The study involved 24 runners (22 males) with a mean age of 24±4 (18 to 34) years, with an average body weight of 67±6 kg, height of 178±7 cm and body mass index of 21±1. Mean systolic blood pressure at rest was 122±8 mmHg and diastolic blood pressure 76±7 mmHg. Resting values of mean HP at the end of preparatory training did not differ significantly from the starting period and were 1059±125 ms and 1048±202 ms, respectively (p=0.9).

Values of VO_2max were significantly higher in the starting period in comparison with the preparatory training period, 61.5±4.9 ml/kg/min *vs* 59.4±5.0 ml/kg/min respectively (p=0.02).

In this homogeneous group of runners, a significant increase in BRS_BA index during the starting period (17.2±8.2 ms/mmHg) *vs* preparatory period (11.5±5.1 ms/mmHg, p=0.0001) was noted. These data are depicted in Figure 1.

The analysis of mean values of HRV indices revealed a significant increase in TP and its corresponding indices of time analysis such as SDNN and pNN50 and also a non-significant trend toward increased RMSSD. Moreover, a statistically significant higher LF index was observed. The values of other HRV indices, especially LFnu and LH/HF, were similar. Specific parameters of short-term HRV are outlined in Table 1.

Discussion

Positive elevation of the parasympathetic activity of ANS in regional class athletes was noted in the study, being a result of long-term preparation for competitions. It is evidenced by obvious changes of ANS profile

Table I. Comparison of mean values of specific heart rate variability indices during preparatory and starting periods in the athletes

	Period of preparatory training	Starting period	p
TP [Ms²]	3384±2298	4364±2614	0.01
SDNN [Ms]	70±36	91±55	0.0002
pNN50 [%]	38±23	48±24	0.03
RMSSD [Ms]	67±37	83±62	0.09
LF [Ms²]	1398±1203	2262±2031	0.002
LFnu [NU]	53±17	55±19	0.14
HF [Ms²]	1506±1240	1906±1276	0.2
LF/HF	1.6±1.3	2.5±3.3	0.1

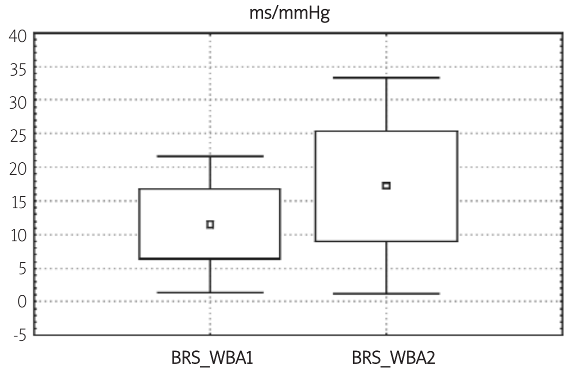

Figure 1. Comparison of BRS values during preparatory training (BRS_WBA1) and the starting period (BRS_WBA2) (p=0.0001)

including such parameters as BRS and indices of short-term HRV, such as TP, SDNN and pNN50.

Similar results have been reported by other authors, regarding however different groups of athletes. For example, Hedelin et al. observed a statistically significant increase in HRV in professional skiers at the end of an intensive 7-month period of endurance training [3]. Iellamo et al. noted a heart rate decrease, elevation of HF and decrease in LF and LF/HF of short-term HRV and also a non-significant trend toward increased BRS during training of a load up to 75% of maximum in rowers preparing for the World Championship [11]. In the report of Portier et al. a reduction in LF and LF/HF of short-term HRV in runners following a 12-week training period were noted [21].

In our report no signs of increased adrenergic activity suggesting overtraining were observed. The only parameter suggesting such overtraining could be the significantly increased LF value, commonly regarded as the sympathetic tone index. There are reports suggesting that overtraining syndrome should be diagnosed solely based on single parameter changes [5, 18, 22]. In our opinion deriving such conclusions about ANS activity is somewhat hazardous, particularly regarding the LF index. As indicated by data from other reports, this parameter reflects not only sympathetic activity but also parasympathetic activity [23, 24]. Moreover, the lack of increases of indices such as LFnu and LF/HF which much better reflect the adrenergic tone of the examined subjects in this study contradicts a diagnosis of overtraining syndrome in our athletes.

Clinical implications

The post-exercise increased parasympathetic activity in a group of regional class athletes engaged in endurance sports (running events) observed herein may be an important argument for promoting this type of physical activity in young and healthy people.

Until now no negative impact of persistent elevation of adrenergic tone on occurrence of intractable ventricular arrhythmias in young healthy subjects has been documented, contrary to studies involving cardiac patients [25-26]. However, in theory such an unfavourable effect could be seen in some athletes with unrecognised structural heart disease. Thus, a lack of clear evidence of persistent increased adrenergic tone in the studied subjects may encourage promotion of intensive and long-term but not maximum physical training in groups of young and healthy people.

Regardless of these remarks the observed patterns of ANS function are not to be interpolated on/extrapolated to other groups of intensively training athletes, including champion class sportsmen, those taking part in competitions closely related to stress, and those engaged in power sports. In such groups further investigations are warranted.

Study limitations

In this report, an analysis of long-term exercise training impact on runners' ANS profile was carried out employing a comparison of BRS and HRV values recorded in the end period of preparatory and in the final period of starting training without estimating the influence of the preparatory training *per se*. This may limit the value of the study. However, the principal aim of this work was to verify the hypothesis that the final phase of a very intensive training cycle during preparation for competitions with exercise loads much more intensive than in the earlier periods would lead to dramatic changes in the autonomic activity with parasympathetic dominance (which may have important clinical implications). Thus a comparison between parameters of the ANS at the end of the starting period and during the training cycle with much less intensive training was performed. The data presented here are part of a more extensive study in which indices of ANS function were also estimated before the onset of the training cycle in most athletes. The findings did not differ significantly from the results of the final period of the preparatory training.

Conclusions

Long-term intensive exercise training employed by regional class runners preparing for competitions changes the autonomic profile, promoting parasympathetic activity. This may be an important argument to encourage many young and healthy people to practise endurance sports at such a level of intensity.

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Wielomiesięczny trening fizyczny poprawia profil autonomicznego układu nerwowego u wyczynowych biegaczy

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Streszczenie

Wstęp: O ile trening wytrzymałościowy umiarkowanego stopnia powoduje wzrost napięcia układu przywspółczulnego, to bardzo intensywne (ekstremalne) obciążenia stosowane u sportowców klasy mistrzowskiej przygotowujących się do zawodów prowadzić mogą do przetrwałego wzmożenia napięcia adrenergicznego. U zawodników klasy regionalnej stosowane obciążenia wysiłkiem zazwyczaj są nieco mniej intensywne.

Cel: Ocena zmian zachodzących w aktywności układu wegetatywnego w grupie biegaczy klasy regionalnej pod wpływem wielomiesięcznego cyklu treningowego przygotowującego ich do startu w zawodach.

Metodyka: Do badań włączono 24 biegaczy klasy regionalnej (22 mężczyzn) w średnim wieku 24±4 (18–34) lat. Oceny spoczynkowej częstości akcji serca (mean HP) oraz czynności autonomicznego układu nerwowego dokonywano w końcowej fazie treningu przygotowawczego (1) oraz w końcowej fazie treningu startowego (2). W tych okresach u każdej osoby przeprowadzano 10-min ciągłą nieinwazyjną rejestrację skurczowego ciśnienia krwi SAP (Finapress, Ohmeda) oraz długości cyklu serca HP (Mingograf 72°C). Na podstawie uzyskanych sygnałów SAP i HP obliczano wrażliwość baroreceptorów tętniczych metodą spektralną (BRS_WBA) oraz poszczególne wskaźniki zmienności rytmu serca (SDNN, pNN50, RMSSD, TP, LF, LFnu, HF, LF/HF).

Wyniki: Stwierdzono istotny statystycznie wzrost wskaźników BRS_WBA, SDNN, pNN50, TP oraz LF w okresie 2 w porównaniu do okresu 1, odpowiednio: 17,2±8,2 *vs* 11,5±5,1 ms/mmHg (p=0,0001), 91±55 *vs* 70±36 ms (p=0,0002), 48±24 *vs* 38±23% (p=0,03), 4364±2614 *vs* 3384±2298 ms^2 (p=0,01), 2262±2031 *vs* 1398±1203 ms^2 (p=0,002), a także graniczny statystycznie wzrost wskaźnika RMSSD: odpowiednio 83±62 *vs* 67±37 ms (p=0,09). Pozostałe oceniane parametry nie różniły się znamiennie statystycznie.

Wnioski: Wielomiesięczny ciężki trening fizyczny zastosowany u biegaczy klasy regionalnej przygotowujących się do startu w zawodach zmienia profil autonomiczny na korzyść składowej przywspółczulnej. Może to stanowić ważny argument zachęcający liczne rzesze młodych zdrowych osób do uprawiania sportów wytrzymałościowych o takiej intensywności.

Słowa kluczowe: wrażliwość baroreceptorów tętniczych, zmienność rytmu serca, trening fizyczny

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