Autonomic Nervous System Recovery After Various Exercises in Highly Trained Athletes

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Abstract

Introduction: Heart rate variability (HRV), expressed by the beat-to-beat variation in heart rate, offers a noninvasive indicator of autonomic nervous system (ANS) activity. Measurement of the ANS response is increasingly used to evaluate the effect of training load on the organism. Most authors compared only the impact of different types of running training sessions (TS) (low-intensity training (LIT), high-intensity interval training (HIIT)), or separately plyometric TS on HRV. In this study, HRV was used to clarify how different types of running TS and plyometric TS influence post-exercise ANS response.

Methods: 12 highly trained runners participated in this study. Each subject completed three types of TS – LIT running, HIIT running and plyometric. 5-min pre-exercise ECGs were recorded just before TS and 5-min post-exercise ECGs were recorded 10 min after TS. Altogether 13 time-domain and frequency-domain HRV features were calculated. Finally, the changes between pre- and post-exercise values of HRV features were computed.

Results: From 13 tested features, 9 and 10 features were statistically significant for distinguishing between plyometrics and LIT, and HIIT and LIT, respectively. There are no statistically significant differences in HRV changes between plyometrics and HIIT. It could be assumed these two TS affect ANS similarly.

1. Introduction

One of the possibilities how to monitor body response to sport training is the evaluation of heart rate variability (HRV). HRV features reflect the autonomic nervous system (ANS) function and thus provide information about reaction of body to sport training. Based on the HRV analysis, it is possible to adjust the training plan and increase the effectiveness of the training. [1]

The autonomous regulation of heart rate (HR) and its acute and chronic adaptation to exercise has been very discussed topics in sport training for the last 20 years [2,3]. The understanding of individual athlete's reactions to different types of training is crucial to remove physiological factors limiting endurance performance [4]. From the essential training variables, exercise intensity and its distribution are probably the most critical and the most heavily debated [3]. If the athlete's reaction to activities is not known, the training schedule cannot be adjusted. Thus, HRV analysis can be very helpful to solve this task.

The application of HRV analysis in sports became easier and affordable thanks to the smart devices such as sport smartwatches or a combination of smartwatch and chest belt. These devices enable electrocardiographic (ECG) and photoplethysmographic (PPG) signal sensing. From these data, HRV features can be calculated. Increased resting HRV is usually associated with the good fitness of the athlete and positive adaptation to endurance training [5]. It manifests subjectively (wellbeing) as well as objectively (e.g. by measuring VO_2max). Decreased HRV corresponds with fatigue or illness [5].

Extensive research has been carried out regarding the general aspects and mechanisms of autonomic cardiovascular regulation during exercise and recovery [3,5,6] in different sports. However, there are only a few studies devoted to comparing ANS responses for different types of sport activities. This is probably because elite athletes primarily train only one specific sport (e.g. long-distance runners train primarily running) to increase their performance. Other sport activities are considered more as active recovery (cycling) or rehabilitation (yoga) or as a targeted increase in muscular strength (strength training, plyometric training) than as the main pillar of the training. That is the reason why researchers do not take into consideration more and various training activities. This means there is no knowledge and experience about the influence of ANS through HRV between different sport activities. Comparing different studies cannot provide correct information, because athletes from specific sport specializations will react to other sport activities differently (e.g. reaction of cyclist on running TS at defined intensity and reaction of runner on the same TS will be different).

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It is important to know how different types of activities (running TS, special TS for a targeted increase of strength, etc.) affect athletes. In this study, HRV was used to clarify how different types of running TS – low-intensity (LIT), high-intensity interval training (HIIT) – and plyometric TS influence post-exercise ANS response.

The evaluation of training response to TS is usually addressed in four ways. First, values of HRV features measured 10 min after TS are calculated [6]. Second, values of HRV features measured the morning after TS (after waking up) are compared with values measured in the morning of the TS day [7]. Third, lnRMSSD is calculated after performing the orthostatic test the morning after TS [8]. Fourth, the change between pre-exercise and post-exercise values of HRV features is calculated [9].

In this study, the fourth method was used. Using this method, it can be accurately evaluated how TS influences ANS. Using any other method, various factors (such as work, psychological stress or sleep) may affect ANS and, thus, distort the results.

2. Methods

2.1. Data collection

Altogether, 12 highly trained runners (18-35 years) participated in this study. Each subject completed some of these three types of TS – LIT running, HIIT running and plyometrics. Specifically, 10 LIT TS (2 athletes performed this TS twice), 12 HIIT TS, 9 plyometric TS (2 athletes performed this TS twice) were performed.

5-min pre-exercise ECGs were taken just before TS and 5-min post-exercise ECGs were taken 10 min after TS. ECG signal was sensed by Bittium Faros 180 ECG device with sampling frequency of 1,000 Hz. From these signals, HRV features were computed.

2.2. Training sessions description

Three types of TS were performed in this study – plyometric TS, LIT TS, and HIIT TS.

The plyometric TS was defined as 10 min warm-up (5 min easy jogging and 5 min stretching) followed by 4 series of 6× basic box jump, 6× squat jump, 6× left leg vertical jump, 6× right leg vertical jump, 6× incline jump and 6× push up with a clap. Finally, the 5 min shakeout was performed. Plyometrics increases neuro-muscular coordination by training the nervous system and making movements more automatic during activity [10,11]. Numerous authors have described increased jump height, reduced sprint time, improved running economy, coordination, and postural control as a result of plyometric training [10,11].

LIT TS was defined as 50 min of easy continuous running at 60-75% of maximal HR (MHR). LIT TS improves mainly cardiovascular performance and endurance and enables better delivery of oxygen to muscles.

HIIT TS was defined as 15 min warm-up (easy running at 60-75% of MHR) followed by 6×2.5 min running at 90-95% of MHR with 2 min rest between intervals, ended by 10 min easy running at 60-75% of MHR. HIIT TS improves mainly the ability to run longer and faster at a higher intensity.

2.3. HRV features extraction

Thirteen different pre- and post-exercise HRV features often used in other studies were calculated [12,13]. The features are described in Table 1 in detail.

Table 1. Description of HRV features used in this study.

Feature	Units	Description
SDNN	ms	The standard deviation of NN intervals. It reflects sympathetic and parasympathetic activities and describes overall variability or total power.
RMSSD	ms	Root mean square of successive NN intervals differences. It describes parasympathetic activity.
lnRMSSD	ms	Natural logarithm of RMSSD. It describes parasympathetic activity.
NN50	count	Number of successive NN intervals that differ by more than 50 ms. It reflects mainly parasympathetic activity.
pNN50	%	Percentage of successive NN intervals that differ by more than 50 ms.
LFpower	n.u.	Low frequency power. Power in frequency band 0.04–0.15 Hz. It reflects sympathetic activity.
HFpower	n.u.	High frequency power. Power in frequency band 0.15–0.4 Hz. It reflects mainly parasympathetic activity.
LFperc	%	Relative LFpower – percentage of LF power to total power.
HFperc	%	Relative HFpower – percentage of HF to total power.
LHratio	-	LF to HF power ratio.
totPower	n.u.	Total frequency power – power in whole frequency band 0–0.4 Hz.
SD1	ms	Standard deviation of the Poincaré plot (short-term variability).
SD2	ms	Standard deviation of the Poincaré plot (long-term variability).

2.3. Statistical analysis

The changes between pre-exercise and post-exercise values of HRV features were computed. They are expressed in percentage of pre-exercise values.

At first, the Shapiro-Wilk test was used to reveal data distribution. The data were not normally distributed. Then, non-parametric Kruskal-Wallis test ($p < 0.05$) was used to find features which are suitable for discrimination between various TS. Finally, a post-hoc analysis ($p < 0.05$) was performed to reveal which pairs of features (TS) showed statistically significant differences.

3. Results

Statistical analysis showed which HRV features differ between TS types. The results (p-values) of post-hoc tests are shown in Table 2. Features which show statistical significance are highlighted in green and blue. From 13 tested features, 9 features were statistically significant for distinguishing between plyometrics and LIT TS. None of the features were statistically significant for distinguishing between plyometrics and HIIT TS. 10 features were statistically significant for distinguishing between HIIT and LIT TS. The boxplots representing the features values (percentage difference between pre-exercise and post-exercise) are shown in Figure 1. All these features (except for LFpower) showed the highest drop in values of such feature after plyometric TS, followed by HIIT TS and the lowest drop (or even increase) showed LIT TS. These features reflect parasympathetic activity or a combination of parasympathetic and sympathetic activity. In contrast, LFpower showed increase for all TS, the most at HIIT, then at plyometric TS, and the lowest increase was at LIT. LFpower reflects mainly sympathetic activity.

Table 2. Table of post-hoc tests p-values. Differences of HRV features were tested between three types (pairs) of TS. Green color indicates statistically significant differences ($p < 0.05$) between Plyo and LIT TS and between HIIT and LIT TS. Blue color indicates statistically significant difference between HIIT and LIT TS only.

Features	Plyo-LIT	Plyo-HIIT	HIIT-LIT
SDNN	0.0003	0.3038	0.0031
RMSSD	0.0041	0.4592	0.0173
NN50	0.0006	0.3798	0.0033
pNN50	0.0008	0.4043	0.0036
LFpower	0.4472	0.7883	0.0361
HFpower	0.0027	0.4611	0.0106
LFperc	0.5578	0.7612	0.8860
HFperc	0.4049	0.5396	0.9355
LHratio	0.4181	0.5868	0.9100
totPower	0.0023	0.6026	0.0033
lnRMSDD	0.0028	0.3993	0.0171
SD1	0.0041	0.4592	0.0173
SD2	0.0002	0.2560	0.0029

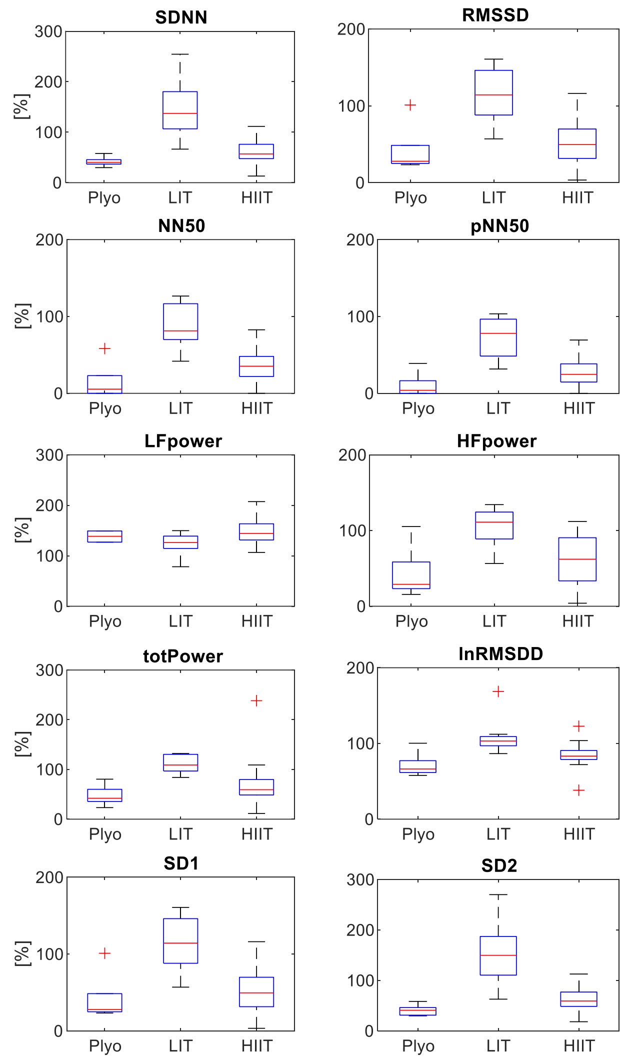

Figure 1. Boxplots of HRV features with statistically significant differences between TS (Plyo – Plyometric, LIT – light-intensity running training, HIIT – high-intensity interval running training). On the y-axis there are differences between pre-exercise and post-exercise values of HRV features expressed in percentage of pre-exercise value.

4. Conclusion

In this study, HRV analysis was used to clarify how different types of running TS (LIT and HIIT) and plyometric TS influence post-exercise ANS response. Firstly, 13 HRV features were computed. Then the difference between pre-exercise and post-exercise values was expressed in percentage of pre-exercise value. Statistical analysis was performed. Kruskal-Wallis test proved that 10 HRV features show statistically significant changes between different types of TS.

More detailed post-hoc tests showed that there are not statistically significant differences in HRV changes between plyometric and HIIT TS. It could be therefore assumed that these two TS affect ANS similarly. 9 and 10 HRV features showed statistically significant differences between plyometric and LIT TS and between HIIT and LIT TS, respectively.

Nowadays, in training practice, it is usually considered that HIIT running sessions lead to the highest load. According to our findings, we assume that plyometric TS and HIIT TS cause similar load for the organism. This finding should be considered when preparing training plans for runners and thus increase the effectiveness of training and prevent injury.

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