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Usefulness of heart rate recovery parameters to monitor cardiovascular adaptation in elite athletes: The impact of the type of sport

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Purpose: The purpose of this study is to determine heart rate (HR) recovery after maximal test in elite athletes who compete in high dynamic, high static, and in mixed sport disciplines; to assess differences in HR recovery between these groups of athletes; and to measure the association of HR index (HRI) with heart adaptation variables to determine whether these values were correlated with the type of exercise. *Methods:* One hundred and ninety-four elite athletes were divided into three groups according to the predominant type of exercise performed: endurance ($n = 40$), strength-sprinter ($n = 36$), and ball-game players ($n = 118$). They performed maximal cardiopulmonary exercise testing on a treadmill and were subjected to echocardiography. The rate of decline (HR recovery) was calculated as the difference between maximum and recovery HRs (HRrec1 and HRrec3). The HRI was calculated as HR_{max} – 1-min post-exercise HR (HRrec1). *Results:* The most significant correlation of HRI was with posterior wall diameter and left ventricular (LV) mass index ($r = 0.43$ and $r = 0.51$; $p = 0.012$ and $p = 0.003$, respectively). LV mass index [Beta (B) = 0.354, $p = 0.001$] was an independent predictor of HRI and HRrec1. HRI may be an effective tool for discrimination of physiological and "gray zone" LV hypertrophy, with area under the curve of 0.545 (95% CI = 0.421–0.669, $p = 0.0432$). HRI displayed a sensitivity of 50% and specificity of 52.2% at the optimal cut-off value of 23.5. *Conclusion:* HR recovery pattern, especially HRI, may offer a timely and efficient tool to identify athletes with autonomous nervous system adaptive changes.

Keywords: heart rate recovery, heart rate index, athlete's heart, cardiovascular adaptation, elite athletes

Introduction

It is well known that regular and intensive physical activity leads to several morphological, functional, and regulatory adaptive heart modifications that have been known as "athlete's heart" (19). The extent of these physiological "adaptive" heart changes is predominantly related to the intensity and kind of sport activity and highly depends on the type of physical training (11).

On the other hand, autonomous regulation of the elite athletes, which is characterized by an enhanced parasympathetic and a decreased sympathetic activity, represents one of the

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most common manifestations of shifted autonomous balance and thus represents a characteristic feature of the athlete's heart (9, 16, 22). It is generally agreed that during exercise there is parasympathetic withdrawal and sympathetic excitation, resulting in heart rate (HR) acceleration, while these effects are reversed during the recovery period (16).

Taking the previously mentioned facts into account, HR alterations, as an autonomic nervous system functional adaptive modification index, can provide valuable information on the autonomic nervous system balance in elite athletes (9).

Thus, HR recovery (HRR) measurement is nowadays widely used in clinical practice as one of the inexpensive, valid, and the most importantly simple indicators of the autonomic nervous system activity. In addition, this parameter is even more important considering the fact that it could be a prognostic manner not only for diseased, but also for the healthy population (13).

Because of previously mentioned facts, nowadays, its use in elite sport is being established due to the well-known "athlete's heart" morphological and functional changes, which are still presented as a "gray zone" between pathology and physiology. Fast HRR is associated not only with better athletic performance, but also with cardiac functional adaptation physical activities of various durations and intensities (17, 18, 25).

To date, studies about athlete's heart primarily include echocardiographic evaluation as a gold standard to detect morphological and functional heart changes (21).

In addition, sometimes, sport practitioners do not have specialized equipment and trained personnel to do precise measurements. On the other hand, the HRR kinetics may be useful as a non-invasive marker to assess autonomic nervous system modulation and to provide important information about several physiological conditions like the athlete's heart (5, 24).

To the best of the authors' knowledge, no study has yet attempted to establish the relationships between HR index (HRI), as a marker of recovery and classical ultrasound variables relevant to heart adaptation in the athletic population. The purpose of this study was to determine HRR after maximal exercise testing in elite athletes who compete in endurance, strength-sprinter, and ball-games sport disciplines; to assess differences in HRR between these groups of athletes; and to measure the association of HRI with heart adaptation variables to determine whether these values were correlated with the type of exercise.

Methods

Participants

One hundred and ninety-four competitive elite male athletes aged 20–30 years from the Serbian Institute of Sport and Sports Medicine volunteered to participate in this study. The study was conducted during regular preparticipation medical screenings in 2016. All trained individuals were divided into three groups according to the predominant type of exercise they perform: endurance (40 participants – long-distance runners and long-distance), strength-sprinter (36 participants – rowers, power lifters, short-distance runners, and martial arts), and ball-game players (118 participants – volleyball, water polo, and football). Elite athlete participants were included in the research study if they met all of the following criteria: (1) being national level athlete at minimum; (2) 15 or more hours of training per week; (3) lack of any history of structural cardiac, cerebrovascular, chronic renal, or hepatic diseases; and (4) none of them was taking any medication or performance enhancing drugs/anabolic steroids at the time of testing. All participants provided a written informed consent to the procedures approved by the Ethics Committee of the School of Medicine, University of Belgrade.

Anthropometric data

Before testing, all the athletes were asked not to eat food or drink caffeine beverages on the test day and to take a light dinner (before 8:00 p.m.) on the day before.

The body weight (BW) and body fat percentage were measured on a scale with 0.01 kg readability (InBody 370, InBody, Seoul, Korea), with participants wearing minimal clothes and being barefoot. Body height (BH) was assessed to the nearest 0.1 cm using a portable stadiometer fixed to the wall. The stadiometer and scale were calibrated periodically during the study.

Body mass index (BMI) was calculated for all the participants as the ratio of mass (kilograms) divided by height (meters) squared.

Ergospiromery test protocol

According to the mandatory and legally prescribed stress-testing protocol for elite athletes, incremental exercise testing was performed on an electronic treadmill ergometer (Treadmill T200, Cosmed, Italy). All the ventilatory parameters were measured continuously using a breath by breath automated ergospirometry system (Cosmed, Quark CPET, Rome, Italy). HR was continuously monitored using a 12-lead electrocardiography (ECG) monitoring. The test consisted of three phases. The first (resting) phase lasted for 3 min and during which the athletes were in a standing position. The second phase started with a speed of 4 km/h, and at the beginning of every subsequent minute, speed strip was increased by 1 km/h. The third (recovery) phase lasted for 3 min. The test was completed when at least three of the four following criteria were met: (1) oxygen consumption plateau (VO_{2max}), (2) attainment of age predicted maximal HR (220 – age), (3) a respiratory exchange ratio higher than 1.1, or (4) athletes' subjective reasons. In the recovery period, HR, systolic blood pressure (SBP), and diastolic blood pressure (DBP) were measured in the first and third minutes of the recovery period.

The HRI was calculated employing the equation: HRI = HR peak – 1-min post-exercise HR (12).

Echocardiography

Echocardiographic measurements of all athletes were performed by a specialist in internal medicine and cardiology who also specialized in sport ultrasonography. Two-dimensional and M-mode Doppler echocardiograms were captured on a Philips CX50 computed sonography platform (Philips, Netherlands) with vector array format transducer having a probe frequency of 3.5 MHz. The protocol followed the recommendations of the American Society of Echocardiography (15). The following parameters were assessed: left ventricular (LV) end-diastolic dimension (EDD) (LVEDD), LV end-systolic dimension (ESD) (LVESD), LV posterior wall diastolic dimension, interventricular septal diastolic dimension (IVSd), ejection fraction (EF), fractional shortening (FS), end-diastolic volume (EDV), end-systolic volume (ESV), and LV mass index. Left ventricular EF was calculated by Simpson's rule. LV mass was calculated using the method described by Devereux et al. (8).

$$\mathrm{LVM} = 1.04 \times \left((\mathrm{LVED} + \mathrm{PWd} + \mathrm{IVSd})^3 - \mathrm{LVED}^3\right) - 13.6\,\mathrm{g}.$$

Relative wall thickness (RWT) was calculated as: (IVSd + PWd)/EDD. As LV mass is known to vary with body size and composition, normalization of LV dimensions according to body size is paramount in comparisons between different subject groups; therefore, adjustments for body size were performed for comparison of cardiac dimensions: all the echocardiographic findings were adjusted to body surface area $(BSA)^{0.5}$ and LV mass was additionally adjusted to $BSA^{1.5}$ (20, 26).

The utility of HRI, as a diagnostic marker for adaptive LV hypertrophy, was examined when all elite athletes were divided into two groups following the recommendations of the American Society of Echocardiography, according to LV mass index cut-off value of 115 g/m^2 (15).

Statistical analysis

Descriptive and analytical statistics were used. For presenting numerical continuous data, arithmetic mean and standard deviation were implemented, after examining the criteria for normal distribution. It was considered that criteria for normal distribution are met if at least one of mathematical methods (coefficient of variation, skewness and kurtosis, Shapiro–Wilk, and Kolmogorov–Smirnov tests) and one of graphical methods (histogram, Q–Q diagram, defriended Q–Q diagram, and box plot) are fulfilled. One-way analysis of variance was used in order to test the difference between three groups (endurance, strength-sprinter, and ball-game players). Pearson's coefficient of linear correlation was performed to test the association between HRI and other variables among all athletes, and within these three groups separately. Multivariable linear regression models were defined with the aim of examining independent predictors for HRI, HRrec1, and HRrec3. Enter method with pretesting the existence of multicollinearity (coefficient of correlation, the variance inflation factor, and tolerance method) between potential predictors was applied. Final model was constructed after elimination of collinear variables. With the aim of testing the utility of HRI, receiver-operator characteristic (ROC) curve (with the estimation of the area under the curve) was constructed (Fig. 1).

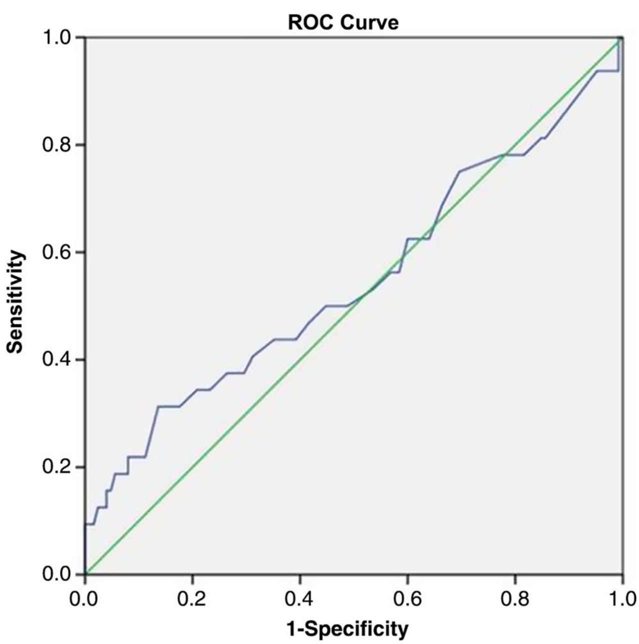

Fig. 1. Receiver-operator characteristic (ROC) curve for HR index in elite athletes

Statistical analyses were performed using SPSS for Windows version 21.0 (SPSS Inc., Chicago, IL, USA). Statistical significance was set for a two-tailed p value <0.05.

Results

Baseline anthropometric characteristics are reported in Table I. Ball-game players are significantly higher compared to the endurance and the strength-sprinter groups ($p < 0.01$). Moreover, ball-game players have significantly higher body mass compared to endurance athletes ($p < 0.01$). There is no significant difference in BSA between the examined groups of athletes (Table I).

Basic cardiovascular and ergospirometry parameters in elite athletes are presented in Table II. There is no significant difference between the majority of examined parameters between the different groups of athletes ($p > 0.05$). Ball-game players have significantly lower resting DBP values than endurance and strength-sprinter athletes. In addition, ball-game players have the lowest VO_{2max} values compared to the other two groups of athletes ($p < 0.01$). The results of this study indicate that ball-game players have significantly lower values of HRR in the first and third minutes, compared to the other groups of sports ($p < 0.01$), implicating that ball-game players and athletes involved in strength-sprinter types of sports show lower recovery values than the endurance group. The endurance group of athletes had significantly lower changes in HR from max to HR3 values (ΔHRR3) compared to strength-sprinters and ball-game players ($p < 0.01$). However, according to our results, there is no statistically significant difference in HRI between examined groups ($p > 0.05$). On the other hand, athletes involved in endurance sport disciplines have significantly lower values of SBP in the first minute of recovery compared to ball-game players ($p < 0.01$).

Basic echocardiographic parameters are presented in Table III. LVEDD, left ventricular end-diastolic volume (LVEDV), left ventricular end-systolic volume, posterior wall (PW), and IVSd are significantly higher in the endurance group of athletes than in ball-game players ($p < 0.001$). In addition, LV mass index and RWT are significantly lower in ball-game players compared to all other athletes ($p < 0.01$).

Correlation between HRI with VO_{2max} values and ultrasound parameters in elite athletes is presented in Table IV. The maximal oxygen consumption values significantly positively

Table I. Anthropometric parameters in elite athletes

	Endurance sports ($n = 40$)	**Strength-sprinter sports ($n = 36$)**	**Ball-game players ($n = 118$)**
Age (years)	24.82 ± 4.6*	25.5 ± 4.4**	22.3 ± 4.4
Body height (cm)	180.6 ± 8.0*	184.4 ± 9.2**	190.2 ± 10.7
Body mass (kg)	77.7 ± 10.1*	83.0 ± 17.0	86.1 ± 13.4
Body mass index (kg/m^2)	23.7 ± 2.2	24.3 ± 4.2	23.7 ± 2.3
Body fat percentage (%)	12.0 ± 5.0	11.3 ± 7.2	12.4 ± 5.5
Body surface area (m^2)	1.97 ± 0.2	2.0 ± 0.2	1.9 ± 0.2

Values are shown as mean ± SD.
*$p < 0.05$ compare endurance sports vs. ball-game players.
**$p < 0.05$ compare strength-sprinter sports vs. ball-game players

Table II. Basic cardiovascular variables and ergospirometry parameters in elite athletes

	Endurance sports ($n = 40$)	**Strength-sprinter sports ($n = 36$)**	**Ball-game players ($n = 118$)**
HRrest (beats/min)	59.4 ± 11.2	59.1 ± 13.1	57.9 ± 9.7
SBPrest (mmHg)	112.1 ± 10.6	114.4 ± 10.8	110.9 ± 11.9
DBPrest (mmHg)	71.9 ± 7.8*	72.3 ± 7.7**	67.5 ± 8.3
VO_{2max} ($ml \cdot min^{-1} \cdot kg^{-1}$)	50.8 ± 5.5*	49.9 ± 5.8**	46.5 ± 5.5
RERmax	1.13 ± 0.1	1.11 ± 0.05	1.13±0.07
HR_{max} (beats/min)	187.6 ± 13.7	184.6 ± 9.2	186.1 ± 9.9
SBPmax (mmHg)	176.2 ± 18.8	183.8 ± 26.3	179.2 ± 21.7
DPBmax (mmHg)	58.2 ± 11.2	58.5 ± 10.4	55.4 ± 14.6
HRrec1 (beats/min)	165.9 ± 13.3*	157.5 ± 19.8	158.8 ± 17.0
HRrec3 (beats/min)	114.0 ± 12.0*	106.4 ± 16.5	106.8 ± 12.2
HRR index (beats/min)	21.5 ± 15.3	25.6 ± 15.7	27.8 ± 13.4
ΔHRR3 (beats/min)	73.2 ± 16.3#	78.2 ± 15.9	81.4 ± 18.0
SBPrec1 (mmHg)	167.8 ± 16.1*	168.4 ± 21.4	176.8 ± 22.1
DBPrec1 (mmHg)	61.2 ± 10.5	59.8 ± 9.9	55.8 ± 15.6
SBPrec3 (mmHg)	141.4 ± 15.2	139.0 ± 14.2	142.3 ± 19.5
DBPrec3 (mmHg)	69.5 ± 7.3	66.2 ± 8.4	66.9 ± 12.1

Values are shown as mean ± SD. HRrest: resting heart rate; SBPrest: resting systolic blood pressure; DBPrest: resting diastolic blood pressure; VO_{2max}: maximal oxygen consumption; RERmax: maximal respiratory quotation; HR_{max}: maximal heart rate; SBPmax: maximal systolic blood pressure; DPBmax: maximal diastolic blood pressure; HRrec1: heart rate recovery at the first minute; HRrec3: heart rate recovery at the third minute; HRI: hear rate recovery index; ΔHRR3: changes in HR from max to HR3 values; SBPrec1 (mmHg): first-minute recovery of systolic blood pressure; DBPrec1: first-minute recovery of diastolic blood pressure; SBPrec3: third-minute recovery of systolic blood pressure; DBPrec3: third-minute recovery of diastolic blood pressure.
*$p < 0.05$ compare endurance athletes vs. ball-game players.
**$p < 0.05$ compare strength-sprinter athletes vs. ball-game players.
#$p < 0.05$ compare endurance vs. strength-sprinter athletes and ball-game players

correlated not only in ball-game players, but also in athletes generally, suggesting that index proposed by the authors of this study could be potentially applicable in everyday clinical practice. Furthermore, the majority of examined echocardiographic parameters significantly correlated with HRI values. Namely, there was a significant positive correlation between HRI and all LV volumes and diameters in the group of athletes predominantly involved in strength-sprinter sport disciplines ($p < 0.05$). The most significant correlation was with PW diameter and LV mass index ($r = 0.43$ and $r = 0.60$; $p = 0.018$ and $p < 0.001$, respectively). On the other hand, LVEDD and LV mass index significantly correlated with HRR index in endurance sport disciplines ($r = 0.35$ and $r = 0.48$; $p = 0.04$ and $p = 0.003$, respectively). When combining all sports together, there was a significant correlation between HRR index

Table III. Echocardiographic variables in elite athletes

	p	**Endurance sports (*n* = 40)**	**Strength-sprinter sports (*n* = 36)**	**Ball-game players (*n* = 118)**
LVEDD (mm)	0.838	55.1 ± 0.6	55.3 ± 0.7	55.5 ± 0.4
LVEDD/BSA$^{0.5}$ (mm/m)	**0.004**	39.2 ± 2.3*	38.5 ± 2.1	38.0 ± 1.7
LVESD (mm)	0.221	35.8 ± 0.5	35.9 ± 0.6	36.8 ± 0.3
LVESD/BSA$^{0.5}$ (mm/m)	0.611	25.5 ± 1.9	25.0 ± 2.1	25.2 ± 1.8
LVEDV (ml)	0.652	152.0 ± 3.8	150.0 ± 4.4	154.3 ± 2.5
LVEDV/BSA$^{1.5}$ (ml/m^3)	**<0.001**	54.7 ± 6.1*	50.6 ± 6.6$^{\#}$	49.3 ± 5.3
LVESV (ml)	0.513	56.5 ± 1.7	54.3 ± 1.9	56.7 ± 1.1
LVESV/BSA$^{1.5}$ (ml/m^3)	<0.001	20.3 ± 2.8*	18.3 ± 3.1$^{\#}$	18.1 ± 2.8
IVSd (mm)	0.208	10.0 ± 0.1	9.7 ± 0.2	9.6 ± 0.1
IVSd/BSA$^{0.5}$ (mm/m)	**<0.001**	7.1 ± 0.6*	6.8 ± 0.7	6.5 ± 0.5
PW (mm)	0.074	10.2 ± 0.2	9.9 ± 0.2	9.7 ± 0.1
PW/BSA$^{0.5}$ (mm/m)	**<0.001**	7.3 ± 0.8*	6.9 ± 0.7	6.6 ± 0.5
LV mass index (g/m^2)	**0.003**	108.7 ± 15.9*	103.7 ± 20.9**	98.1 ± 14.7
LV mass/BSA$^{1.5}$ (g/m^3)	**<0.001**	39.5 ± 7.8*	35.2 ± 6.8$^{\#}$	31.6 ± 5.3**
Ejection fraction (%)	0.402	62.6 ± 0.7	62.7 ± 0.6	61.8 ± 0.4
FS (%)	0.189	35.2 ± 1.1	33.5 ± 0.5	34.5 ± 0.3
RWT	**0.049**	0.36 ± 0.03*	0.35 ± 0.04	0.34 ± 0.03

Significant values are represented in bold. Values are shown as mean ± SD. *p* values are obtained according to one-way ANOVA. LVEDD: left ventricle end-diastolic diameter; LVESD: left ventricle end-systolic diameter; LVEDV: left ventricular end-diastolic volume; LVESV: left ventricular end-systolic volume; IVSd: interventricular septum end-diastolic; PW: posterior wall; FS: fractional shortening; RWT: relative wall thickness; BSA: body surface area
*$p < 0.05$ compare endurance athletes vs. ball-game players.
**$p < 0.05$ compare strength-sprinter athletes vs. ball-game players.
$^{\#}p < 0.05$ compare endurance vs. strength-sprinter sports players

and LVEDD, LVESD, LVEDV, IVSd diameter, PW thickness, and LV mass index ($r = 0.352$, $r = 0.261$, $r = 0.296$, $r = 0.383$, $r = 0.389$, and $r = 0.46$; $p < 0.001$, respectively). The main observation of the results is that all correlations obtained in this study were even more prominent after the normalization of all examined echocardiographic parameters according to BSA (BSA$^{1.5}$, BSA^1, or BSA$^{0.5}$).

Determinants of BP values, cardiorespiratory functional capacity, and echocardiographic parameters

The multivariate linear regression models for predictors of HRI, HRR1, and HRR3 are presented in Table V.

Table IV. Correlation between heart rate index with VO_{2max} values and ultrasound parameters in elite athletes

	Endurance sports ($n = 40$)		**Strength-sprinter sports ($n = 36$)**		**Ball-game players ($n = 118$)**		**All sports**	
	r	***p***	***r***	***p***	***r***	***p***	***r***	***p***
VO_{2max}	0.123	0.480	−0.288	0.123	**0.247**	**0.032**	**0.315**	**0.023**
LVEDD (mm)	**0.330**	**0.049**	**0.373**	**0.032**	−0.045	0.670	**0.172**	**0.031**
$LVEDD/BSA^{0.5}$ (mm/m)	**0.349**	**0.040**	**0.502**	**0.005**	0.182	0.144	**0.352**	**<0.001**
LVESD (mm)	0.203	0.236	**0.378**	**0.030**	−0.153	0.151	0.091	0.255
$LVESD/BSA^{0.5}$ (mm/m)	0.014	0.934	0.270	0.150	**0.397**	**0.001**	**0.261**	**0.003**
LVEDV (ml)	0.053	0.759	**0.345**	**0.049**	−0.048	0.653	0.066	0.412
$LVEDV/BSA^{1.5}$ [m (L/m^3)]	0.194	0.265	**0.617**	**<0.001**	**0.396**	**0.001**	**0.442**	**<0.001**
LVESV (ml)	0.162	0.346	**0.381**	**0.029**	−0.079	0.462	0.102	0.200
$LVESV/BSA^{1.5}$ (ml/m^3)	0.240	0.164	**0.479**	**0.007**	**0.452**	**<0.001**	**0.440**	**<0.001**
IVSd (mm)	0.277	0.102	**0.474**	**0.005**	0.015	0.890	**0.177**	**0.026**
$IVSd/BSA^{0.5}$ (m/m)	0.185	0.287	**0.450**	**0.013**	**0.324**	**0.008**	**0.383**	**<0.001**
PW (mm)	0.194	0.258	**0.430**	**0.012**	0.014	0.897	0.148	0.063
$PW/BSA^{0.5}$ (mm/m)	0.209	0.228	**0.429**	**0.018**	**0.352**	**0.004**	**0.389**	**<0.001**
LV mass index (g/m^2)	**0.359**	**0.031**	**0.508**	**0.003**	0.046	0.669	**0.234**	**0.003**
LV mass/$BSA^{1.5}$ (g/m^3)	**0.481**	**0.003**	**0.601**	**<0.001**	**0.256**	**0.040**	**0.460**	**<0.001**
Ejection fraction (%)	0.087	0.614	−0.153	0.396	0.007	0.949	0.007	0.929
FS (%)	−0.013	0.948	0.012	0.955	0.096	0.404	0.021	0.812
RWT	−0.028	0.871	0.318	0.071	0.039	0.717	0.057	0.473

Significant values are represented in bold. Values are Pearson's correlation values. VO_{2max}: maximal oxygen consumption; LVEDD: left ventricle end-diastolic diameter; LVESD: left ventricle end-systolic diameter; LVEDV: left ventricle end-diastolic volume; LVESV: left ventricle end-systolic volume; IVSd: interventricular septum end-diastolic; PW: posterior wall; FS: fractional shortening; RWT: relative wall thickness; BSA: body surface area

After the adjustment for age and exclusion of all the variables, which were in correlation with potential predictors, LV mass index [Beta $(B) = 0.354$, $p = 0.001$] was independent predictor of HRI and HRrec1. Namely, our results pointed to a positive correlation with the HRI ($p = 0.001$), but significant negative correlation with HR rec1 ($p = 0.018$).

ROC analysis of HRI for assessing severity of heart adaptive changes

To assess the severity of heart adaptive changes in elite athletes involved in different types of physical activity, ROC curves analysis was conducted. ROC curve and the corresponding area indices were calculated for HRI. The optimal cut-off values were analyzed for HRI with a p value of ≤ 0.05. Figure 1 shows that HRI may be a potential differentiating parameter between physiological and "gray zone" LV hypertrophy, with area under the curve of 0.545

Table V. Multivariate linear regression models for predictors of HRI, HRrec1, and HRrec3 after adjustment for age

Predictors	***B***	β	**95% CI for *B***	***p***
For HRI				
SBPrec1	−0.139	−0.154	−0.28 to −0.01	0.058
LV mass index	0.354	0.310	0.15 to 0.56	**0.001**
RWT LV	−28.430	−0.046	−137.09 to 80.23	0.606
For HRrec1				
SBPrec1	0.035	0.046	−0.09 to 0.16	0.574
LV mass index	−0.212	−0.221	−0.39 to −0.04	**0.018**
RWT LV	−3.956	−0.008	−97.33 to 89.42	0.933
For HRrec3				
SBPrec1	−0.085	−0.136	−0.19 to 0.02	0.103
LV mass index	−0.116	−0.147	−0.26 to 0.03	0.113
RWT LV	7.730	0.018	−70.12 to 85.58	0.845

Significant values are represented in bold. HRrec1: heart rate recovery at the first minute; HRrec3: heart rate recovery at the third minute; HRI: heart rate recovery index; CI: confidence interval; SBPrec1: first-minute recovery of systolic blood pressure; RWT: relative wall thickness; LV: left ventricle; BSA: body surface area

(95% CI = 0.421–0.669, $p = 0.0432$). HRI displayed a sensitivity of 50% and specificity of 52.2% at the optimal cut-off value of 23.5.

Discussion

This is the first study to demonstrate the data of HRR after a maximal treadmill exercise test and its correlation with fitness level (measured and assessed using VO_{2max} values) and echocardiographic parameters in elite athletes, with respect to different types of physical activity. The most important result of the study is that not only the type of training, but also the HRR pattern, has an impact on the adaptive heart changes in elite athletes.

In addition, this is the first study that compares and contrasts different HRR patterns in elite athletes according to different types of physical activity. This fact is even more significant, considering the importance of HR measurements in everyday clinical practice, and its usefulness, especially when there is no available equipment to complete ergospirometry testing and measure fitness level directly, using VO_{2max} values.

Moreover, one of the advantages of this study is the unique ergospirometry testing protocol that was used in order to give the most precise data about the HRR in different groups of elite athletes. The testing protocol used in this study represents a special benefit of this study, concerning the fact that there were no biomechanical advantages/disadvantages between athletes during testing as can be seen during other performance and fitness testing protocols, such as the Harvard step test or its modifications (Sloan test). Namely, the main disadvantages of the previously mentioned tests are the significant differences in the obtained results that are mostly because of the different biomechanical characteristics of the tested athletes. Some of the first studies dealing with this issue showed that, considering that the step height is standard, taller people are at an advantage as it will take less energy to step up onto the step. BW has also been shown to be a factor (23).

In addition, the results of this study that used the previously mentioned exercise testing protocol are even more important remembering the fact that, in case of elite athletes, who are all with almost perfect endurance capacity, even small variation could substantially change the results of the study that could entail the false positive or negative conclusions.

Furthermore, since maximal cardiopulmonary exercise testing is widely used in assessing performance and preparticipation screening of elite athletes, the association of physical performance estimated using this testing protocol with HRR pattern could find valuable role in the everyday clinical practice (4).

The results of ergospirometry testing showed that ball-game players had significantly lower resting DBP values as compared to the other two groups of elite athletes. On the other hand, VO_{2max} values were significantly lower in ball-game players in comparison to other groups.

In addition to the previously mentioned differences, there were significant differences in HRR values according to the type of sport. Although our results showed no differences in HRI values according to the different types of physical activities, there were statistically significant differences in HRR patterns. Namely, ΔHRR3 was significantly different between endurance and strength-sprinter athletes, pointing to the faster recovery in elite athletes involved in strength-sprinter sport activities.

Previously mentioned facts are in accordance with one of the author's previously published studies. The differences in the resting and recovery blood pressure values may be explained by the well-known physiological background – the concentric and static phase of muscle contraction, characteristic for strength-sprinter trainings, mechanically compresses the peripheral arterial blood vessels that supply active muscles leading to significant increase of total peripheral resistance. These changes induce the sympathetic nervous system activation and increase mean arterial pressure. On the other hand, changes in blood pressure values in endurance athletes and ball-game players, as presenters of more endurance type physical activity, are the consequence of increased blood flow during their activity, which rapidly increases SBP during the first few minutes, but, as activity continues, SBP gradually declines, while DBP remains relatively constant (10).

Another importance of our results is the significant positive correlation between VO_{2max} values and HRI, implicating that HRR pattern may be a potentially useful cardiovascular fitness level measuring parameter in elite athletes. In addition, the results of this study proposed an optimal cut-off value that could be used as an indicator of the level of aerobic capacity in elite athletes. The usefulness of the proposed cut-off value is even more important considering that, according to the results of this study, there was a strong positive correlation between VO_{2max} values and HRI values. Thus, our results put HRR pattern in elite athletes into a different perception. Namely, previous studies showed that HRR represents a complex interaction between autonomic and numerous humoral factors (6). The fact that HRR is associated with a fine autonomic balance, while VO_{2max} is mostly connected with enhanced sympathetic activity, put HRI into a different perspective. Namely, fine autonomic balance, with the parasympathetic predomination, represents not only the main difference between athletes and sedentary people, but also could be used in training-induced disturbances and as a training prescription method in elite athletes (6).

Namely, literature data point on the fact that cardiovascular and neurovegetative adaptations to continuous and intense physical activity are presented through different HRR patterns. Adaptive simpatovagal balance changes in elite athletes lead to higher HRR values not only when comparing athletes to a sedentary population, but also when comparing different types of physical activities (18, 24).

On the other hand, the importance of our results is even larger considering the significant correlation between HRI, as the most commonly used convalescence parameter, and different LV morphological and functional changes. In other words, although the majority of examined echocardiographic parameters significantly correlated with HRI values, the most significant correlation was with PW diameter and LV mass index in athletes predominantly involved in strength-sprinter sport disciplines. Also, LV mass index was shown to be a significant independent predictor of HRI and HRrec3.

Through previously mentioned correlations established in this study, the authors want to point to its potential clinical importance in everyday practice.

Namely, post-exercise HR variability pattern monitoring is nowadays widely used in clinical practice as one of the inexpensive, valid and, the most importantly, simple indicators of the autonomic nervous system activity (6). Thus, measuring the 3-min HRR pattern with the usage of different recovery indices to calculate the post exercise recovery quality may be one of the useful tools to distinguish different levels of athlete's physical fitness and adaptive heart changes, especially in cases when traditional "gold standard" diagnostic tools are not available for measuring cardiovascular adaptation to physical activity.

Additionally, maximal cardiopulmonary exercise testing is a routine protocol, which is used not only as part of the preparticipation screening, but also in assessing performance. However, to date, there is no real-time and easily obtained predicting tool, which is used to identify athletes whose heart is physiologically adapted or even who are at risk of adverse effects of intensive physical activity using only this examination.

On the other hand, the results of this study point to the facts that although echocardiography is widely used in order to define the heart adaptation model according to the predominant type of physical activity (concentric vs. eccentric hypertrophy), nowadays these differences are less observable. Taking the previously mentioned facts into account, magnetic resonance imaging could be more useful, but its application is rather expensive and therefore unprofitable. This information makes us to discover more informative, but cost-effective and easily applicable parameters to estimate early heart adaptation in elite athletes.

To the best of the authors' knowledge, this is the first study to evaluate not only HRR pattern in different types of physical activity, but also to specifically address its usefulness as a diagnostic tool in heart adaptive changes in elite athletes.

Our data demonstrate that LV heart adaptation evaluated by LV mass index can be distinguished clearly by the athletes' HRI patterns. Although the athletes involved in endurance types of physical activities showed the most prominent adaptive morphological heart changes, the highest positive correlation was established between HRI and LV dimensions in strength-sprinter athletes. However, according to the results, the authors may point to the most significant power of HRI as a measure of overall HRR process. Namely, our results of the ROC curve analysis pointed that, in elite athletes, HRI has the highest discrimination power between the groups of elite athletes.

Moreover, although in the literature, some studies examined HRR values in elite athletes, the most of these data are not useful in everyday clinical practice because different protocols are used for its assessment. In order to overcome this issue, we used maximal incremental exercise protocol and calculated HRR as the absolute value of the decrease in HR peak to rates measured 1 and 3 min after exercise. This approach has been recently proposed as the preferred, consistent, and uniform method for HRR reporting (1).

The results of this study point to the fact that HRI may find its place and significance in everyday practice as a reliable and fast diagnostic tool, which can predict LV mass index in elite athletes involved in different types of physical activity. Namely, we have found that HRR pattern, as presented by HRI, can be a useful screening tool for (risk-assessment of) heart phenotypes in elite athletes involved in different types of physical activity.

Whether these HRR patterns are also useful for assessing the risky adaptive or "gray zone" heart phenotypes in active young people, or even athletes who are at the increased risk for sudden cardiac death, is a subject of further investigation. However, to date, there is no adequate measurement system for a rapid, inexpensive, and safe determination of the volume of adaptive cardiovascular changes, considering the fact that they are present not only after a short period of intensive physical activity, but also in very young athletes due to their early specialization. Previously mentioned facts are even more important with the point that physical exertion can be of any type of physical exercise, e.g., treadmill exercise, as described in this study; thus, HRR can be measured not only using ECG, but also it can be estimated by a Sport Tester or manually. Finally, its calculation can be chosen by the investigator, following the most economic and the easiest method. HRI meets these criteria. Based on the good discrimination results obtained from the present data set, HRR pattern measurements are likely to contribute to this interesting field in further studies.

Usefulness of determination of HRR pattern in elite athletes

In the literature, many studies emphasize different and very useful utilizations of HR kinetics. Namely, it is widely used in detection of training-induced disturbances in autonomic control and training prescription. In addition, it finds its advantages in determining the training state and detecting training-associated misbalances, mainly presented as fatigue, overtraining, and dehydration (14). Additionally, it is well known that HRR pattern, as a more sensitive marker than HR variability, could be helpful during the training-response monitoring process and it is especially appreciated during sport-specific training prescription in elite athletes (5).

Furthermore, significant positive correlation between HRR pattern and different echo-cardiographic indices, especially those that describe LV adaptive hypertrophy in athletes involved in different types of physical activities, may be a novel and useful tool with potentially significant role in everyday clinical practice.

One more advantage of HRI is the fact that elite athletes exposed to vigorous physical activity are at increased risk of malignant arrhythmias, and sudden cardiac death is its potential usage as a diagnostic screening tool in the evaluation of the cardiovascular risk among elite athletes (2, 3, 7).

Conclusions

This study provides novel and important information on HRR values after maximal exercise test in the population of elite athletes with respect to age and different types of physical activity. In addition, this study points to the fact that HRR pattern, especially HRI, may offer a timely and efficient tool to identify athletes with early LV adaptive changes.

Despite early promising results, practical applications of HRR in elite athletes, such as assessment of the early LV adaptive changes or even the risk of malignant arrhythmias or SCD, need to be established.

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Conflict of interest

The authors declare no conflict of interest.

Abbreviations

ANOVA	: analysis of variance
B	: beta coefficient
BH	: body height
BMI	: body mass index
BW	: body weight
CI	: confidence interval
DBP	: diastolic blood pressure
EDD	: end-diastolic dimension
EDV	: end-diastolic volume
EF	: ejection fraction
ESD	: end-systolic dimension
ESV	: end-systolic volume
FS	: fractional shortening
HR	: heart rate
HRI	: heart rate index
IVSd	: interventricular septal diastolic dimension
LV mass index	: left ventricular mass index
PWd	: posterior wall diastolic dimension
RER	: respiratory exchange ratio
ROC	: receiver-operator characteristic
RWT	: relative wall thickness
SBP	: systolic blood pressure
VIF	: variance inflation factor
VO_{2max}	: oxygen consumption plateau

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