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The impact of high intensity interval training and moderate intensity continious training regimes on cardiodynamic parameters in isolated heart of normotensive and hypertensive rats

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Abstract

This study was aimed to assess the impact of high intensity interval training (HIIT) vs. moderate intensity continious training (MIT) on cardiodynamic parameters in isolated rat heart. Wistar albino rats were randomly assigned to groups according to running protocol: sedentary control (CTRL), MIT, HIIT; spontaneous hypertensive sedentary control (SHR), spontaneous hypertensive rats (SHR) + MIT and SHR + HIIT. HIIT groups performed the running in 5 sprints x 45-55m/min for 30-90sec, with 2 mins rest after each sprint, while MIT groups performed the running of 10-15m/min for 1h with 3 mins rest/100m, both protocols were implemented 5 days/week over 4 weeks with one week of adaptation before protocols started. Isolated rat`s hearts were perfused according to Langendorff technique at gradually increased coronary perfusion pressures (40–120 cmH_2O). Using sensor placed in the left ventricle, we registered: maximum and minimum rate of pressure development in the left ventricle, systolic and diastolic left ventricular pressure and heart rate. Coronary flow was measured flowmetrically. MIT was connected with cardiac depression in normotensive conditions, while HIIT leads to cardiac depression in hypretensive rats. HIIT induced more significant increase of contractile and relaxation parameteres of the isolated rat heart, especially in hypertensive animals.

Key words: physical training, treadmill, cardiodynamics, coronary flow, isolated rat heart.

Introduction

Physical exercise has been shown to reduce many cardiovascular risk factors and is associated with a number of cardiovascular benefits. Benefits include improved serum lipid profiles, blood pressure and inflammatory markers as well as reduced risk of stroke, acute coronary syndrome and overall cardiovascular risks and to the improvement the quality of life (Jolliffe et al. 2001; Artero et al. 2013; McCormack et al. 2014). Although regular exercise training has been confirmed as a pragmatic and sustainable countermeasure for cardioprotection, the precise underlying mechanisms, especially in hypertensive conditions, remain to be defined.

Current international physical activity guidelines recommend that all children and young people should accumulate at least 60 min of moderate-to-vigorous physical activity each day, and have acknowledged that vigorous-intensity activities provide further health benefits (O'Donovan et al. 2010). Moderate-intensity, high-volume continuous aerobic exercise has been recommended for the inactive public, yet youth activity is spontaneous, high intensity and intermittent in nature (Bailey et al. 1995). Movement away from the idea of accumulating at least 10-min bouts of moderate-intensity aerobic activity to fulfil the current physical activity recommendations has lead research to investigate more nuanced approaches to achieve the health benefits of physical activity. These new advances in research aim to understand the importance of light-intensity incidental body movement and the impact of reducing sedentary behaviour, but equally look to understand the benefits of higher intensities of activity (Carson et al. 2014).

Regular physical exercise is considered to be one of the beneficial factors of a proper lifestyle and is nowadays seen as an indispensable element for good health, able to lower the risk of disorders of the cardiovascular diseases (Farah et al. 2017). High intensity interval training (HIIT) presents shorter periods of high intensity (sub- to near maximal) exercise

followed by longer periods of low intensity exercise or rest (Hakansson et al. 2018; O'Driscoll et al.1985). On the other hand, traditional training methods for cardiovascular health tended to focus on longer-duration sessions involving moderate intensity exercise performed continuously without rest, often termed moderate-intensity training (MIT) (Costa et al. 2018; Green et al. 2014).

A growing body of evidence has demonstrated comparable or superior improvements in cardiometabolic health outcomes using HIIT as compared to MIT (Gibala et al. 2012). It has been shown that HIIT led to similar enhancement in skeletal muscle metabolic adaptations, cardiovascular fitness, vascular function, and body composition comparing to MIT in humans (Burgomaster et al.2008; Gibala et al. 2006).

American heart association suggests at least 5 times per week some physical activity in duration of 30-60 minutes, plus 2 times a week of strength training and a special program for patients at increased risk. Physical activity should take 150-180 minutes per week, and individual adjustment is important. Complementing aerobic training can be training for flexibility and coordination, the so-called dosed dynamic power training with a high repetition rate and reduced intensity (Leon et al. 2005).

Furthermore, investigations combining and comparing influence of exercise with different duration and intensity are insufficient. Therefore, the objective of this study was to estimate effects of HIIT and MIT training on cardiodinamic parameters and coronary flow in normotensive and hypertensive rats as well as compare obtained results between these training protocols.

Material and methods

Animals and design of the study

Male *Wistar albino* rats, 8-week-old (*n* = 72; body weight: 270 ± 50 g) were kept on an artificial 12-h light-dark cycle (8:00 a.m.− 8:00 p.m.) at room temperature (23 ± 0.5 °C) in the Institute of Cardiovascular Physiology, Faculty of Medical Scienes, University of Kragujevac. The animals were housed in their respective groups in a collective cage and water and food were available *ad libitum*. After 1 week of preconditioning feeding and 1 week of preconditioning running regimen, all rats were randomly assigned to three groups: sedentary control (CTRL, n = 12), MIT (n = 12), HIIT (n = 12), spontaneous hypertensive sedentary control (SHR, n = 12), SHR + MIT (n = 12) and SHR + HIIT (n = 12).

Compliance with Ethical Standards

The experimental protocol was approved by the Faculty of Medical Sciences Ethics Committee for the welfare of experimental animals, University of Kragujevac, number 01-13340/1 and by Ministry of Agriculture, Forestry and Water Management, Authority for Veterinary of Serbia number 323-07-04422/2017-05 and followed the Guidelines for the Care and Use of Laboratory Animals.

Exercise protocols

Exercise protocols were performed by Treadmill for rats (ELUNIT Medical Equipment) which is a treadmill customized for anatomical and physiological characteristics of small experimental animals (power supply 220 V, 50 Hz, number of trails for running: 4; Speed control 2-50 m/min with a resolution of 0.1 m/min) which is connected with Treadmil-software to monitoring speed continiously.

Two different modes of continious exercise training were used on rats: MIT and HIIT. The exercise HIIT group ran on treadmill for four weeks—five days a week with one week before of adaptation period (8 m/s speed for 30 min/day), and then in second week they run 5 sprints from 45-49 m/min for 30 seconds, in third week 5 sprints with 50 m/min speed, in fourth week 5 sprints with speed from 51-55 m/min and in the last week 5 sprints with 55 m/min with longer duration. Before each training session 5 mins warmup at 8 m/min and after each spint rest for 2 mins was conducted (Table 1).

The rats on exercise MIT protocol ran on treadmill for four weeks-five days, with one week before of adaptation period (8 m/s speed for 30 min/day), and with gradual increase in speed during weeks, from 10 m/min in second week to 15 m/min in fifth week with 3 mins rest/100 m and 5 mins warmup at 8 m/min prior to each training session (Table 2).

Isolated rat heart preparation

After short ketamine/xylazine narcosis, emergency thoracotomy was performed, and hearts of male Wistar albino were attached to Langendorff apparatus via aortic cannula. The hearts were retrogradely perfused according to the Langendorff technique at gradually increased with perfusion pressure (40 cmH_2O–120 cmH_2O). The hearts were perfused with Krebs-Henseleit solution, which were composed of: NaCl 118 mM, KCl 4.7 mM, $CaCl_2$ x $2H_2O$ 2.5 mM, $MgSO_4$ x 7 H_2O 1.7 mM, $NaHCO_3$ 25 mM, KH_2PO_4 1.2 mM, glucose 5.5 mM, equilibrated with 95% O_2/5% CO_2 and warmed to 37 °C (pH 7.4). Immediately after the establishment of automatic operation, a latex balloon was inserted into the left chamber, through the incision of the left atrium and destroyed mitral valve. The balloon (large enough that pressure was not generated over the LV volume used in experiment) was filled with bubble-free saline and connected to a pressure sensor (transducer BS4 73-0184,

Experimentria Ltd, Hungary) for continuous recording of the parameters of myocardial function.

Physiological assay and experimental protocol

After heart perfusion commenced, a 30 min period was allowed for stabilization of the heart. After an equilibration period (70 cmH_2O), CPP was lowered to 60 cmH_2O and then gradually increased to 80 cmH_2O, 100 cmH_2O, and 120 cmH_2O, and finally lower to 40 cmH_2O. The flow was considered to be stable at each value of perfusion pressure, when three repeated values of coronary flow (CF) were the same. CF was measured flowmetrically. Using sensor placed in the left ventricle, we registered the following parameters of myocardial function which were continuously recorded in the control and experimental groups:

a) maximum rate of left ventricular pressure development (dp/dt max);

b) minimum rate of left ventricular pressure development (dp/dt min);

c) systolic left ventricular pressure (SLVP);

d) diastolic left ventricular pressure (DLVP);

e) heart rate (HR) and

f) coronary flow (CF).

Statistical analyses

Values were presented as the mean ± standard error mean. Prior to statistical analysis, all data were checked for normality using the one-sample Kolmogorov-Smirnov test. Biochemical data were evaluated using one-way analysis of variance (ANOVA). Comparisons of the training protocols of each group were conducted by one-way ANOVA followed by Tukey's post-hoc test with false discovery rate (FDR) correction. One-way

ANOVA followed by Tukey's post-hoc test was used to analyze other measures. These analyses were carried out using MedCalc statistical software version 17.9 (Acacialaan 22, 8400 Ostend, Belgium 2018) and SPSS statistical program version 22.0. The level of statistical significance for all analyses was 95% ($p < 0.05$).

Results

The effects of HIIT and MIT training on the cardiodynamic parameters of isolated rat heart

dp/dt max

In normotensive rats, dp/dt max was significantly increased in CTRL group over the entire CPP range compared to MIT and HIIT groups. dp/dt max was the most significantly decreased by MIT training at all CPP, compared to CTRL and HIIT groups (Fig. 1A). In hypertensive groups, dp/dt max was significantly decreased in SHR+MIT group at CPP 60-120 cmH_2O compared to SHR and SHR+HIIT groups. dp/dt max was significantly increased in SHR+HIIT group at CPP 60 cmH_2O and 80 cmH_2O compared to SHR, while at CPP 100 cmH_2O and 120 cmH_2O became significantly decreased compared to SHR (Fig. 1B).

dp/dt min

Significant increasment of dp/dt min was observed in CTRL group over the entire CPP range compared to MIT and HIIT group of normotensive rats. dp/dt min was significantly reduced in MIT group at all CPP, compared to CTRL and HIIT groups (Fig. 2A). While in hypertensive groups, significantly the lowest dp/dt min was observed in SHR+HIIT group over the entire CPP range compared to SHR group, and at CPP 100 cmH_2O compared to SHR+MIT group (Fig. 2B).

SLVP

Values of SLVP were significantly decreased in HIIT group at CPP 60 cmH_2O, 100 cmH_2O and 120 cmH_2O compared to CTRL and MIT groups. Significantly increased of SLVP was observed in MIT group at the at CPP 60 cmH_2O and 100 cmH_2O, and decreased at CPP 120 cmH_2O compared to CTRL of normotensive animals (Fig. 3A). In hypertensive groups, significant increase of SLVP was observed in SHR+MIT group over the entire CPP range compared to SHR and SHR+HIIT groups. Also, significantly increased values of SLVP was observed in SHR+HIIT group in comparation to SHR group at all CPP (Fig. 3B).

DLVP

In normotensive rats, DLVP was significantly increased in MIT group over the entire CPP range compared to CTRL and HIIT groups. Significant reduction of DLVP was observed in CTRL group at all CPP compared to MIT and HIIT groups (Fig. 4A). A similar trend existed in hypertensive groups. DLVP was increased in SHR+MIT group at CPP 60-120 cmH_2O compared to SHR and SHR+HIIT groups. While the lowest DLVP was observed in SHR group at CPP 60-120 cmH_2O compared to in SHR+MIT and SHR+HIIT groups (Fig. 4B).

Heart rate (HR)

HR was quite uniform in normotensive rats. Significantly increased values of HR wereobserved in HIIT group at CPP 80 cmH_2O and 120 cmH_2O compared to MIT and CTRL groups. HR was increased at CPP 80 cmH_2O compared CTRL group (Fig. 5A). In hypertensive groups, significant reduction of HR was observed in SHR at CPP 100 cmH_2O and 120 cmH_2O compared to values in SHR+MIT and SHR+HIIT groups. Also, HR was

significantly increased in SHR+HIIT group at CPP 100 cmH_2O, and decreased at CPP 120 cmH_2O compared to in SHR+MIT (Fig. 5B).

Coronary flow (CF)

Significant increasment in values of CF was observed in CTRL group at CPP 80-120 cmH_2O compared to MIT and HIIT groups. On the other hand, significant reduction of CF was observed in HIIT group at the same CPP compared to MIT and CTRL groups (Fig. 6A). In hypertensive groups, significant increased of CF was observed in SHR+MIT at all CPP compared to in SHR and SHR+HIIT groups (Fig. 6B).

Discussion

The present study aimed to examine the effects of HIIT and MIT on heart function and perfusion in hypertensive and normotensive rats as well as compared the obtained results between these running protocols.

Primary task of our investigation was to assess exercise induced changes in mechanics of hearts isolated from hypertensive and normotensive rats. It is known that hypertension induces considerable cardiac remodelling, such as hypertrophy, interstitial fibrosis, and abnormal activity of the cardiac sympathetic nervous system, which are established risk factors in several highly dangerous heart diseases, such as ventricular fibrillation and congestive heart failure. In that sense, the benefits of aerobic training to hypertensive subjects are well established in the literature (Sharman et al. 2015; Rodrigues et al. 2018). Regarding that it is of interest to assess the type of physical activity wich can be beneficial in hypertensive conditions. It has been shown that aerobic training reduces apoptosis in the myocardium of SHRand improves contractile function of cardiomyocytes isolated from the left ventricle (Rodrigues et al. 2018). Hovewer, little is known about precise interval and

intensity of physical training which can be beneficial or on other hand harmful, and where is it that border between positive and negative impact of physical activity on heart function.

To evaluate myocardial contractility, we used dp/dt max (Fig. 1A, B) as indirect indicator of inotropic properties of the heart while dp/dt min was measured as rate of relaxation of the heart (Fig. 2A, B). Our results regarding dp/dt max show that in normotensive rats both types of running weakened contractile force of the heart. On contrary, in condition of hypertension, MIT rise contractile response only at lower CPP. Finally, in contrast to normotensive rats where both type of training depleted dp/dt max, in hypertensive ones MIT protocol induced stronger contractile power. Relaxing parameter of the myocardium is in accordance with inotropic characteristics, pointing out that, HIIT and MIT in normotensive as well as hypertensive rats, decreasing the power of contraction diminishes the relaxation of the myocardium. Namely, this reduction speaks in favor of impaired diastolic function of the heart. In contrast to our findings, MacDonnell and coworkers using Langendorff apparatus found that exercise training in hypertension improves the inotropic and lusitropic responsiveness to beta-adrenergic receptor stimulation despite augmenting LV wall thickness (MacDonnell et al. 2005). HIIT, improved systolic capacity in normotensive rat, contrary to hypertensive rats where effect of this physical activity decreased systolic capacity (Fig. 3A, B). On the other hand, diastolic function of the normotensive as well as of hypertensive animals was improved by both running protocols, suggesting that filling of left chamber may be better (Fig. 4A, B). Elevated left ventricular end-diastolic pressure may or may not be associated with systolic dysfunction and it can suggest diastolic dysfunction in the absence of reduced ejection fraction (Salem et al. 2006). Two weeks of HIIT enhanced endothelial function and heart rate variability without improvements in traditional CVD risk factors. However, most of this favorable adaptation was lost 3 days after training cessation, suggesting that regularly performing high-intensity exercise is needed to maintain these

benefits (Bond et al. 2015). HIIT protocol had almost no influence on HR in normotensive groups. In hypertension groups, HIIT or MIT protocols also did not much influence on heart frequency, which had a wider range of variances at all CPP (Fig. 5A, B). These results suggest that exercise protocol was insufficiently long to induce training bradycardia as a well-established consequence of endurance exercise training (D'Souza et al. 2014). The most of prevous studies, hypothesized that the HIIT training would be more effective than MIT at improving endothelial function and maximum oxygen uptake (VO_{2max}). All of that aims are in the basis of fact that HIIT more affect endothelial finction and has higher metabolic benefit than other physical trainig. However, because of diversity of experimental models, there are inconsistent results.

Improved heart function in hypertensive rats after MIT is proved by the highest coronary flow. This could be a result of higher demand for oxygen supply and thus better perfusion in hypertensive rats during MIT (Fig. 6A, B). The highest level of coronary perfusion in SHR+MIT group seems to be quite logic, having in mind that physical activity that lasts longer may stimulate release of another potent vasodilator-adenosine, due to lower level of ATP in the cells (the effect known as exercise-induced coronary vasodilation) (Duncker et al. 1998). Constraints of our study refer to the absence of histological and biochemical analyses which could bring a new dimension and help in the explanation of collected results. However, we focused only on the functional changes of MIT or HIIT. Our results also pointed out that different running regimes alter reactivity of coronary endothelium and thus perfusion of the heart.

Finally, clinical importance of this research is reflected in accentuate the myocardial and coronary response to short exercise protocols. Therefore, obtained experimental data can be excellent basis for other preclinical and human investigation in this field.

Conclusion

The findings of present study may be of interest in better understanding of medium - to - high intensity exercise - induced direct effects on cardiac function and perfusion. MIT seems to be connected with cardiac depression in normotensive conditions, while HIIT leads to cardiac depression in hypretensive conditions. The main conclusion of this research is that running of both training protocols change myocardial function and perfusion in hypertensive and normotensive conditions. From the aspect of comparison between two protocols of exercise, it was observed that HIIT induced more significant increase of contractile and relaxation parameteres of the isolated rat heart, especially in hypertensive animals.

Abbreviations

CF – coronary flow; CPP – coronary perfusion pressure; HIIT - high intensity interval training; HR – heart rate; MIT - moderate intensity continious training; SEM - standard error mean; SHR - spontaneous hypertensive sedentary.

Acknowledgments

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Figure Captions List

Figure 1. Values of maximum rate of left ventricular pressure development (dp/dt max) during coronary autoregulation of the isolated rat hearts after different training protocols, **A** (normotensive rats), **B** (hypertensive rats). Values were presented as the mean ± standard error mean. Comparisons of the training protocols of each group were conducted by one-way ANOVA followed by Tukey's post-hoc test. Statistically significant difference between groups (p<0.05) is marked as ***a*** CTRL *vs.* MIT; SHR *vs.* SHR+MIT; ***b*** HIIT *vs.* CTRL; SHR *vs.* SHR+HIIT; ***c*** MIT *vs.* HIIT; SHR+MIT *vs.* SHR+HIIT.

Figure 2. Values of minimum rate of left ventricular pressure development (dp/dt min) during coronary autoregulation of the isolated rat hearts after different training protocols, **A** (normotensive rats), **B** (hypertensive rats). Values were presented as the mean ± standard error mean. Comparisons of the training protocols of each group were conducted by one-way ANOVA followed by Tukey's post-hoc test. Statistically significant difference between groups (p<0.05) is marked as ***a*** CTRL *vs.* MIT; SHR *vs.* SHR+MIT; ***b*** HIIT *vs.* CTRL; SHR *vs.* SHR+HIIT; ***c*** MIT *vs.* HIIT; SHR+MIT *vs.* SHR+HIIT.

Figure 3. Systolic left ventricular pressure (SLVP) values during coronary autoregulation of the isolated rat hearts after different training protocols, **A** (normotensive rats), **B** (hypertensive rats). Values were presented as the mean ± standard error mean. Comparisons of the training protocols of each group were conducted by one-way ANOVA followed by Tukey's post-hoc test. Statistically significant difference between groups (p<0.05) is marked as ***a*** CTRL *vs.*

MIT; SHR *vs.* SHR+MIT; ***b*** HIIT *vs.* CTRL; SHR *vs.* SHR+HIIT; ***c*** MIT *vs.* HIIT; SHR+MIT *vs.* SHR+HIIT.

Figure 4. Diastolic left ventricular pressure (DLVP) values during coronary autoregulation of the isolated rat hearts after different training protocols, **A** (normotensive rats), **B** (hypertensive rats). Values were presented as the mean ± standard error mean. Comparisons of the training protocols of each group were conducted by one-way ANOVA followed by Tukey's post-hoc test. Statistically significant difference between groups (p<0.05) is marked as ***a*** CTRL *vs.* MIT; SHR *vs.* SHR+MIT; ***b*** HIIT *vs.* CTRL; SHR *vs.* SHR+HIIT; ***c*** MIT *vs.* HIIT; SHR+MIT *vs.* SHR+HIIT.

Figure 5. Heart rate (HR) values during coronary autoregulation of the isolated rat hearts after different training protocols, **A** (normotensive rats), **B** (hypertensive rats). Values were presented as the mean ± standard error mean. Comparisons of the training protocols of each group were conducted by one-way ANOVA followed by Tukey's post-hoc test. Statistically significant difference between groups (p<0.05) is marked as

a CTRL *vs.* MIT; SHR *vs.* SHR+MIT; ***b*** HIIT *vs.* CTRL; SHR *vs.* SHR+HIIT; ***c*** MIT *vs.* HIIT; SHR+MIT *vs.* SHR+HIIT.

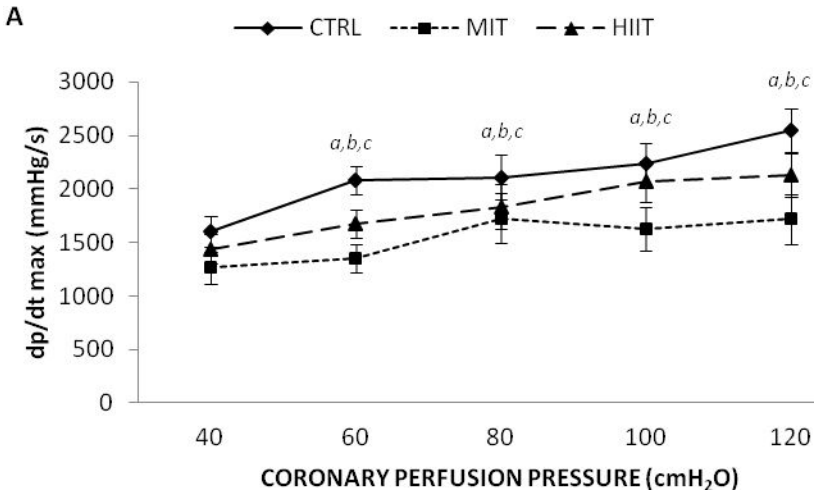
Figure 6. Values during coronary autoregulation of the isolated rat hearts after different training protocols, **A** (normotensive rats), **B** (hypertensive rats). Values were presented as the mean ± standard error mean. Comparisons of the training protocols of each group were conducted by one-way ANOVA followed by Tukey's post-hoc test. Statistically significant difference between groups (p<0.05) is marked as ***a*** CTRL *vs.* MIT; SHR *vs.* SHR+MIT; ***b*** HIIT *vs.* CTRL; SHR *vs.* SHR+HIIT; ***c*** MIT *vs.* HIIT; SHR+MIT *vs.* SHR+HIIT.

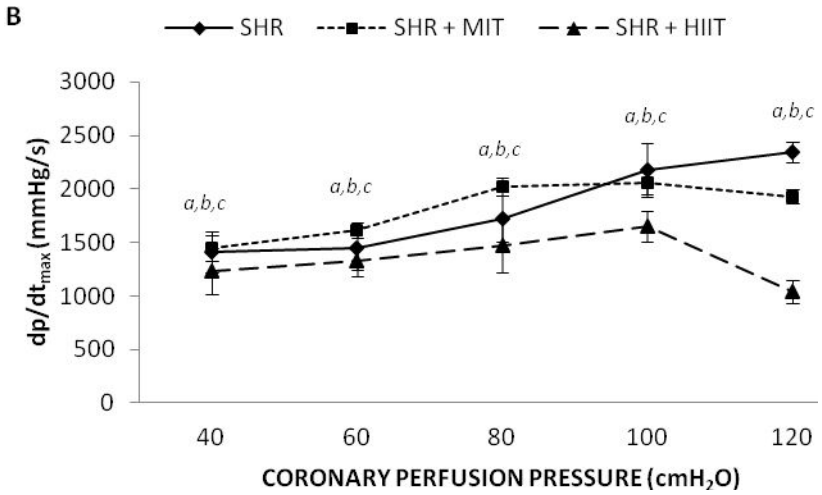
Table 1. Protocol for high intensity interval training for rats (HIIT)

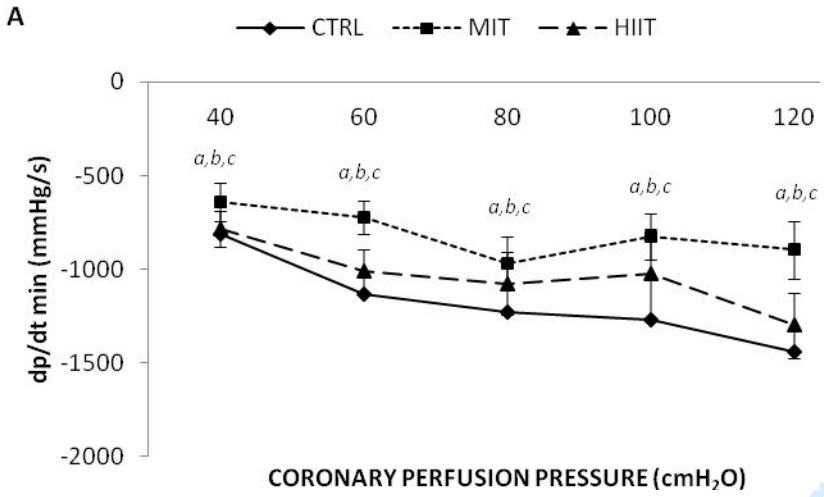
Weeks/Days	**Mo**	**Tu**	**We**	**Th**	**Fr**
1	8m/min for 30min				
2	5 sprints x 45m/min for 30sec	5 sprints x 46m/min for 30sec	5 sprints x 47m/min for 30sec	5 sprints x 48m/min for 30sec	5 sprints x 49m/min for 30sec
3	5 sprints x 50m/min for 30sec	5 sprints x 50m/min for 40sec	5 sprints x 50m/min for 45sec	5 sprints x 50m/min for 55sec	5 sprints x 50m/min for 60sec
4	5 sprints x 51m/min for 60sec	5 sprints x 52m/min for 60sec	5 sprints x 53m/min for 60sec	5 sprints x 54m/min for 60sec	5 sprints x 55m/min for 60sec
5	5 sprints x 55m/min for 65sec	5 sprints x 55m/min for 70sec	5 sprints x 55m/min for 75sec	5 sprints x 55m/min for 80sec	5 sprints x 55m/min for 90sec
*2 mins rest after each sprint					
**5 mins warmup at 8m/min prior to each training session					

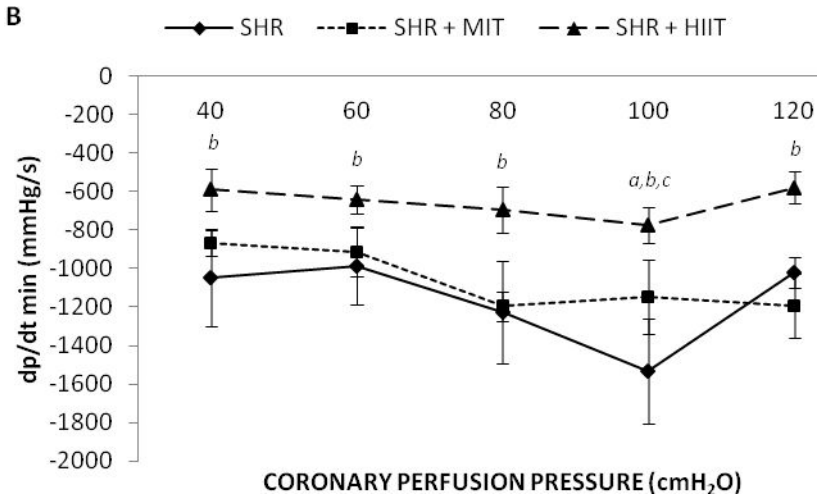
Table 2. Protocol for moderate interval continious training for rats (MIT)

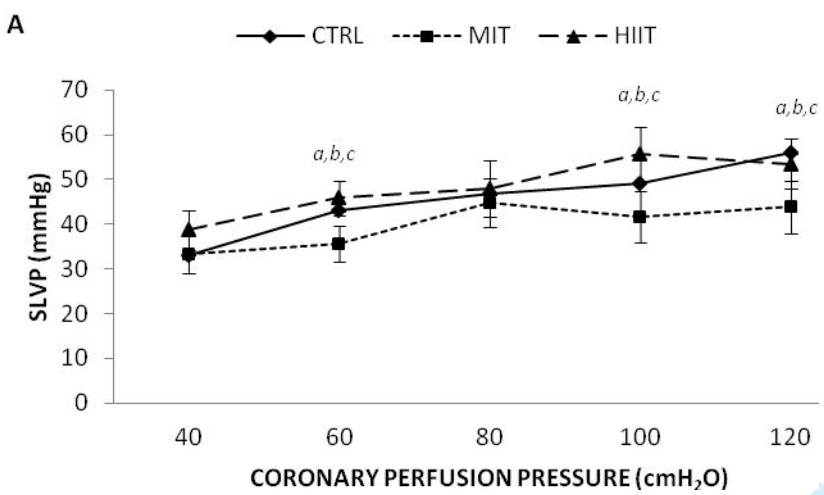
Weeks/Days	**Mo**	**Tu**	**We**	**Th**	**Fr**
1	8m/min for 30 min				
2	10m/min for 1h	10m/min for 1h	10m/min for 1h	10m/min for 1h	10m/min for 1h
3	12m/min for 1h	12m/min for 1h	12m/min for 1h	12m/min for 1h	12m/min for 1h
4	13m/min for 1h	13m/min for 1h	13m/min for 1h	13m/min for 1h	13m/min for 1h
5	15m/min for 1h	15m/min for 1h	15m/min for 1h	15m/min for 1h	15m/min for 1h
*3 mins rest/100m					
**5 mins warmup at 8m/min prior to each training session					

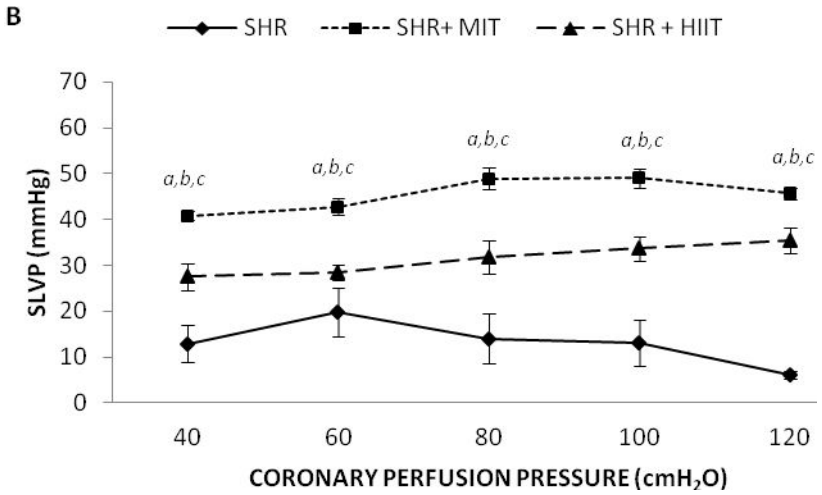

A
CTRL
MIT
HIIT
dp/dt max (mmHg/s)
3000
2500
2000
1500
1000
500
0
a,b,c
40
60
80
100
120
CORONARY PERFUSION PRESSURE (cmH2O)

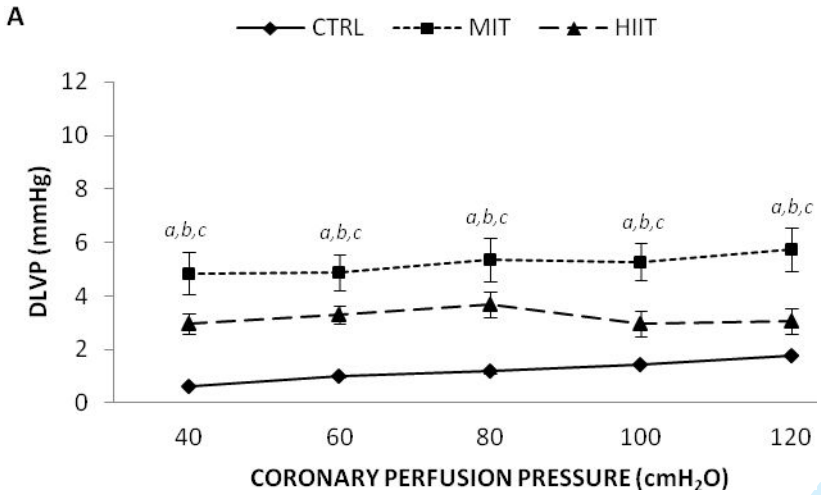

B
SHR
SHR + MIT
SHR + HIIT
dp/dtmax (mmHg/s)
3000
2500
2000
1500
1000
500
0
a,b,c
40
60
80
100
120
CORONARY PERFUSION PRESSURE (cmH2O)

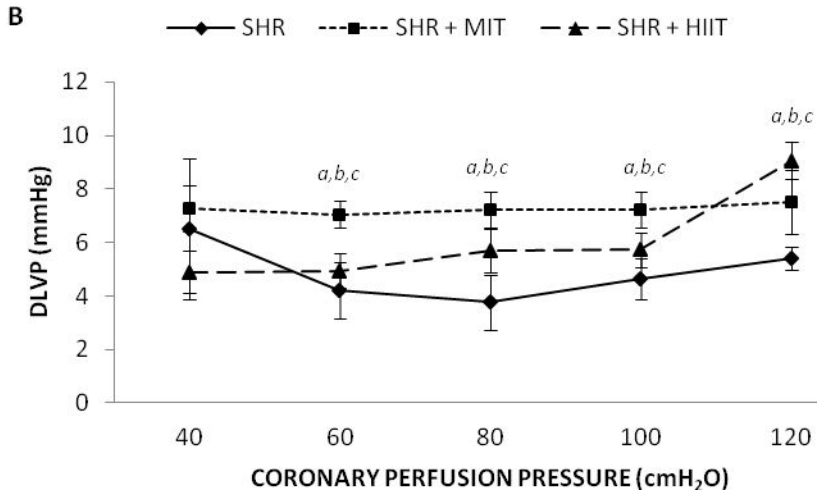

A
CTRL
MIT
HIIT
0
-500
-1000
-1500
-2000
dp/dt min (mmHg/s)
40
60
80
100
120
a,b,c
a,b,c
a,b,c
a,b,c
a,b,c
CORONARY PERFUSION PRESSURE (cmH2O)

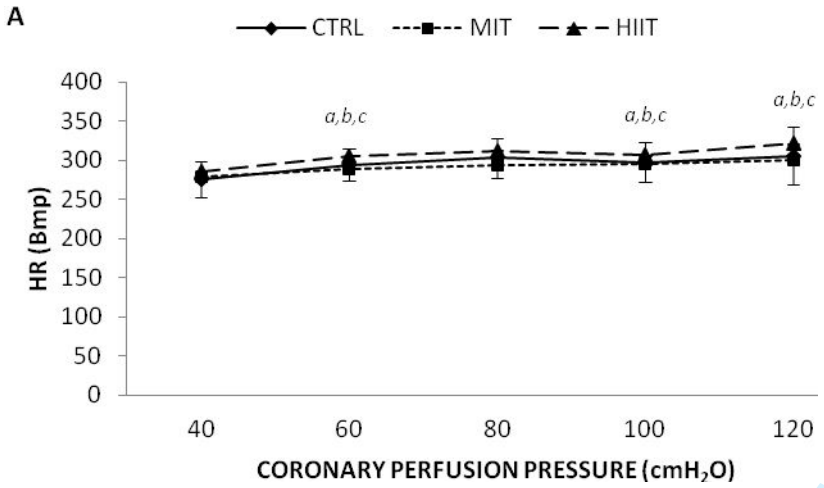

B
SHR
SHR + MIT
SHR + HIIT
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
dp/dt min (mmHg/s)
40
60
80
100
120
b
b
b
a,b,c
b
CORONARY PERFUSION PRESSURE (cmH2O)

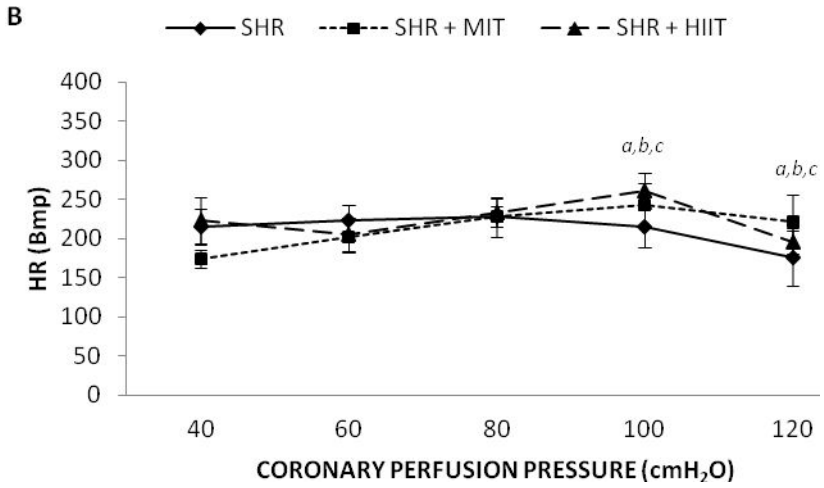

A
CTRL
MIT
HIIT
SLVP (mmHg)
CORONARY PERFUSION PRESSURE (cmH2O)
a,b,c

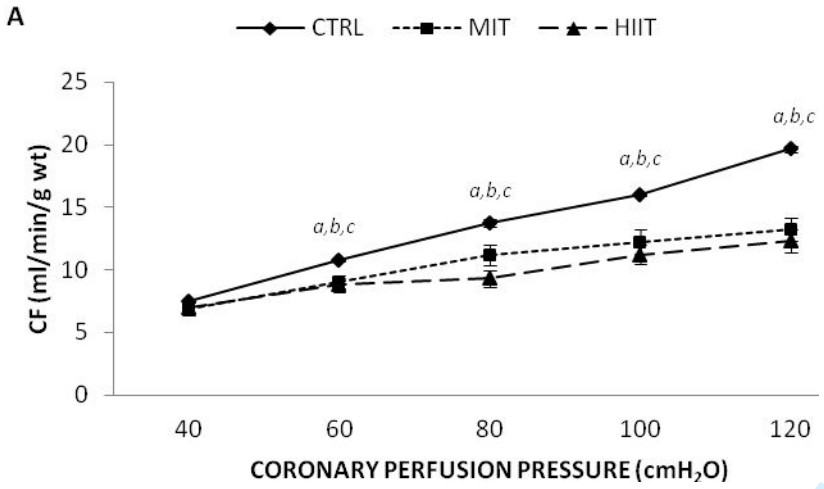

B
SHR
SHR+ MIT
SHR + HIIT
SLVP (mmHg)
CORONARY PERFUSION PRESSURE (cmH2O)
a,b,c

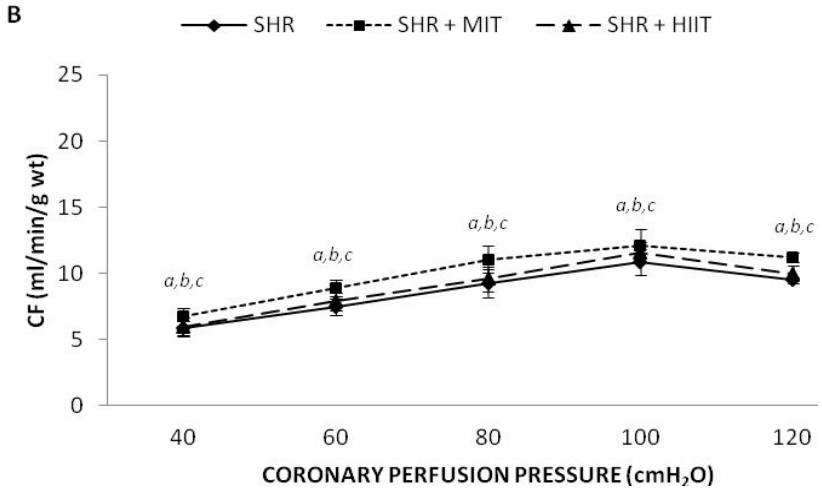

A
CTRL
MIT
HIIT
DLVP (mmHg)
12
10
8
6
4
2
0
a,b,c
a,b,c
a,b,c
a,b,c
a,b,c
40
60
80
100
120
CORONARY PERFUSION PRESSURE (cmH2O)


B
SHR
SHR + MIT
SHR + HIIT
DLVP (mmHg)
12
10
8
6
4
2
0
a,b,c
a,b,c
a,b,c
a,b,c
40
60
80
100
120
CORONARY PERFUSION PRESSURE (cmH2O)


A
CTRL
MIT
HIIT
400
350
300
250
200
150
100
50
0
HR (Bmp)
a,b,c
a,b,c
a,b,c
40
60
80
100
120
CORONARY PERFUSION PRESSURE (cmH2O)


B
SHR
SHR + MIT
SHR + HIIT
400
350
300
250
200
150
100
50
0
HR (Bmp)
a,b,c
a,b,c
40
60
80
100
120
CORONARY PERFUSION PRESSURE (cmH2O)


A
CTRL
MIT
HIIT
CF (ml/min/g wt)
25
20
15
10
5
0
40
60
80
100
120
CORONARY PERFUSION PRESSURE (cmH2O)
a,b,c


B
SHR
SHR + MIT
SHR + HIIT
CF (ml/min/g wt)
25
20
15
10
5
0
40
60
80
100
120
CORONARY PERFUSION PRESSURE (cmH2O)
a,b,c