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The Effect of Heart Rate Variability Biofeedback Training on Optimizing Blood Pressure after Exercising in Cold Environment in 14-15-Year-Old Adolescents

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Abstract

Background: The heart rate variability biofeedback (HRV-BF) method is designed to activate both vagal nerve activity and baroreflex function. The present study aimed to determine the relation between the expression of the spectral power of the dominant peak of the HRV low-frequency (LF) band, its time period, and the degree of blood pressure decrease in 14-15-year-old adolescents who performed short-term HRV-BF training after physical exercise in a cold environment.

Methods and Results: Thirty healthy 14–15-year-old males were examined. The study included the baseline stage, physical activity in the cold, post-exercise stage, recovery stage—HRV-BF training (the HRV-BF group, n=20), or resting stage (the control group, n=10). In the control group, systolic blood pressure (SBP) did not change significantly at any examination stage. In the HRV-BF group, the SBP level was significantly lower in the recovery stage than at baseline (110.0 [108.0;117.0] mmHg and 115.0 [110.0;128.0] mmHg, respectively, P=0.008), which occurred against the background of an increase in the LF band (2.16 [0.94; 4.62] ×1000, ms^2 versus 0.75 [0.47;0.92]×1000, ms^2 in the control group, P<0.01) and spectral power of the maximum LF peak (LFmx) (97.9 [32.5;247.6] ms^2/Hz versus 33.5 [23.6;46.1] ms^2/Hz in the control group, P<0.05).

Conclusions: Short-term HRV-BF training to enhance the overall HRV after exercise in the cold provides a more pronounced reduction in post-load elevated SBP than in the group without this training, against the background of an increase in the HRV LF band and spectral power of the maximum peak of the LF band.**(International Journal of Biomedicine. 2024;14(4):686-690.)**

Keywords*:* heart rate variability biofeedback • cold • adolescents • blood pressure

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Abbreviations

BP, blood pressure; **DBP**, diastolic blood pressure; **HRV**, heart rate variability; **HRV-BF**, heart rate variability biofeedback; **LF**, low-frequency; **SBP**, systolic blood pressure.

Introduction

A high prevalence of arterial hypertension in residents of the Arctic region due to exposure to low temperatures has been found.[1-3] Sports activities in young people in the open cold air promote the integration of the circulatory and respiratory systems to maintain health, preventing vascular tone disorders. Therefore, developing preventive measures designed to improve cardiac functional reserves in people active in the open cold air to minimize the risk of cold hypertension appears to be a contemporary topic.[4] The heart rate variability biofeedback (HRV-BF) method is designed to activate both vagal nerve activity and baroreflex function.[5-7] Preservation of baroreflex reactivity provides a reduction of arterial hypertension severity and maintenance of arterial pressure within normal limits.[8] Previous studies have shown that in 14-15-year-old adolescents, using a short-term HRV-

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BF session after exercise at a comfortable temperature (indoors) promotes an increase in vagal activity reserves of heart rate regulation, but without significant differences in blood pressure (BP) compared to the control group.[9] After similar physical activity in cold air, when BP significantly increased, its decrease was more significant after the HRV-BF session against the background of unchanged vagal activity.[10] Thus, the optimizing effect of short-term HRV-BF training after exercise in a cold environment was primarily on changes in hemodynamics and, to a lesser extent, on changes in autonomic nervous tone. It is considered that the greatest effect of HRV-BF training is possible when the respiratory rate is slowed down and when the resonance frequency of HRV reaches 0.1 Hz (respiratory period of 10 seconds, 6 respiratory cycles per minute).[11] However, exposure to cold combined with physical activity causes an increased and prolonged need of the organism for adrenal receptor activation, angiotensin and aldosterone secretion, increased oxygen requirement, which induces a person to breathe more frequently and superficially, and performing breathing movements with such a rare frequency causes additional stress for the person.[1] This is especially expressed in adolescents because they have an incomplete age-related formation of the cardiorespiratory coupling system.[12] Therefore, to achieve the effect of muscle relaxation and comfortable breathing, contributing to the increase in total HRV during biofeedback training, a person performs breathing movements with a possible frequency and depth of breathing. In healthy people with preserved cardiorespiratory coupling and respiratory deceleration of less than 9 respiratory cycles per minute, there is a shift of the dominant HRV peak to the HRV low-frequency (LF) band (0.15-0.04 Hz), reflecting baroreflex activity, [13] which helps to maintain BP at an optimal level.

The aim of the present study was to determine the relation between the expression of the spectral power of the dominant peak of the HRV LF band, its time period, and the degree of BP decrease in 14-15-year-old adolescents who performed short-term HRV-BF training after physical exercise in a cold environment.

Materials and Methods

A cross-sectional, non-randomized analytical controlled trial was performed at secondary school No.20 in Arkhangelsk in January and February 2019-2020. Inclusion criteria were male students of the 8th grade (aged 14-15 years), healthy according to the results of medical observation, attending the group for physical education without restrictions on physical activity, and the availability of informed parental consent for the study. Exclusion criteria were acute respiratory infection at the time of the study, musculoskeletal disorders, chronic diseases in the history, physical limitations, height and body mass index above the 97th and below the 3rd percentile (height-for-age and BMI-for-age scales for the respective age and gender).[14]

After applying the criteria for matching the sample, two groups were formed: the HRV-BF group (n=20) and the control group (n=10).

The study with the registration of physiological parameters (SBP, DBP, HRV) included baseline stage, the previous HRV-BF training session (these data were not taken into account in this study), performing physical exercise in the cold, post-exercise stage and the recovery stage (performing HRV-BF training for 3 min) or the resting stage (3 min, the control group) with the registration of HRV, SBP and DBP parameters. Thus, preliminary HRV-BF training was carried out by participants in both groups, but only participants in the HRV-BF group additionally carried out it after the exercise in the cold. All measurements took place in the morning indoors, both before and after physical activity in the open air. Physical speed and strength exercise was performed in the form of a special test: a long jump from a place three times in cold conditions on the school playground. The air temperature was from -1 to - 15^{0}C with wind speed of 6 - 10 m/sec ("Sanitary and Epidemiological Requirements to the Conditions and Organization of Education in General Education Schools," document No.2.4.2.2821-10)

Students performed three long jumps from a place with maximal effort; the protocol recorded the best result. The maximum tension of the body muscles of the explosive character (in a short period of time) was manifested during this load of speed-force character.[15] Jump length was measured from the jump line to the nearest body touch point. Before the test, students performed a warm-up with light jogging (3 min - 4-5 km/hour), stretching leg muscles, and turning the body sideways (2 min). A biofeedback training session was conducted using a "Varicard" device ("Ramena LLC," Russia) with electrodes on the extremities (I standard electrocardiogram lead) by visual control on the computer monitor of the graph and numerical index of Total Power (TP), which was updated every 4 sec.

Participants were informed in advance that if the session was successful (muscle relaxation, slower breathing, deeper inhalation, and longer exhalation than in the background), the TP values should increase.

HRV indices were recorded indoors near the place of going outside to the school playground where the physical activity was performed. HRV parameters were recorded in 3-minute sessions with the following parameters: heart rate (HR - bpm); TP (Total Power, ms^2) - total power of the HRV spectrum (0.003-0.40 Hz), reflecting both the total variability of heart rhythm and vagal influences on heart rhythm in short recordings (up to 5 minutes); SI (units) - index of sympathetic activity (according to Baevsky); LF (low-frequency band, 0.15-0.04 Hz); LFmx (spectral power of dominant (maximal) peak of LF, ms^2), LFperiod (period of dominant peak of the HRV LF band). SBP and DBP (mmHg) were recorded using an A&D device (Japan).

Statistical analysis was performed using the statistical software package STATISTICA v.12 (StatSoft Inc., USA). The normality of distribution of continuous variables was tested by Shapiro-Wilk's W test. Median (Me) and interquartile range (IQR; 25th to 75th percentiles) were calculated. Quantitative variables of independent groups were compared using the Mann-Whitney U-criterion. A probability value of $P<0.05$ was considered statistically significant. The Wilcoxon test was used to compare the dependent groups with Bonferroni correction (P<0.017). The Spearman correlation coefficient (r_s) was used to assess the relationships between variables.

Results

The jump distances in the control group and the HRV-BF group did not differ statistically: 199(188;213) cm and 190(173;197) cm, respectively (P>0.05), which indicates comparable efforts during physical exercise in the groups. In individuals in the control group, a decrease in SBP after exercise was observed at the recovery stage, but this decrease did not reach the required reliability (P<0.017) (Table 1).

In the HRV-BF group, the SBP level was significantly lower in the recovery stage than at baseline (110.0 [108.0;117.0] mmHg and 115.0[110.0;128.0] mmHg, respectively, P=0.008). HR was higher in the HRV-BF group than in the control group but did not reach the levels of significant tachycardia.

At the same time, HR during the recovery stage in the HRV-BF group was statistically comparable to that in the control group (P>0.05). Such a relative increase in HR may reflect the baroreflex response to a significant decrease in BP. In both groups, DBP did not change significantly in the dynamics. In the HRV-BF group, total HRV, according to the TP index, was significantly higher in the recovery period than in the post-exercise stage (P=0.007).

Table 1.

Cardiovascular parameters in 14–15-year-old adolescents after exercise in the cold (Me (25;75)).

Parameter	Baseline stage	Post-exercise stage	Recovery stage	*P*-value
	1	2	3	
	Control group (n=10)			
SBP, mmHg	125.0 (112.0; 135.0)	153.0 (140.0; 155.0)	122.0 (117.0; 124.0)	P_{1-2} = 0.043 P_{1-3} =0.345 P_{2-3} =0.043
DBP, mmHg	71.0 (66.0; 76.0)	90.0 (74.0; 90.0)	75.0 (70.0; 79.0)	P_{1-2} =0.138 P_{1-3} =0.172 P_{2-3} =0.345
HR, bmp	85.8 (77.0; 90.0)	87.1 (79.8; 98.4)	86.0 (80.5; 94.7)	P_{1-2} =0.600 P_{1-3} =0.600 P_{2-3} =0.916
TP × 1000, ms^2	3.27 (1.56; 4.90)	1.94 (1.03; 6.40)	2.08 (1.28; 2.64)	P_{1-2} =0.753 P_{1-3} =0.115 P_{2-3} =0.463
SI, units	93.0 (72.5; 244.7)	165.2 (116.6; 300.0)	137.2 (76.4; 175.6)	P_{1-2} =0.345 P_{1-3} =0.463 P_{2-3} =0.600
LF× 1000, ms^2	1.0 (0.72;1.67)	0.67 (0.52;1.38)	0.75 (0.47; 0.92)	P_{1-2} =0.463 P_{1-3} =0.345 P_{2-3} =0.463
LFmx, ms^2/Hz	36.4 (21.8; 54.3)	30.5 (20.4; 39.9)	33.5 (23.6; 46.1)	P_{1-2} =0.600 P_{1-3} =0.753 P_{2-3} =0.753
LFperiod, sec	10.1 (7.94; 16.52)	8.9 (8.5; 11.6)	9.4 (9.2; 9.8)	P_{1-2} =0.916 P_{1-3} =0.463 P_{2-3} =0.916
	HRV-BF group (n=20)			
SBP, mmHg	115.0 (110.0; 128.0)	140.5 (133.0; 152.0)	110.0 (108.0; 117.0)	P_{1-2} =0.001 P_{1-3} =0.008 P_{2-3} =0.001
DBP, mmHg	74.0 (66.0; 78.0)	76.0 (70.0; 79.0)	75.0 (69.0; 77.0)	P_{1-2} =0.277 P_{1-3} =0.779 P_{2-3} =0.492
HR, bmp	75.5 (67.4; 89.3)	77.3 (72.6; 92.5)	84.7 (79.1; 92.1)	P_{1-2} =0.420 P_{1-3} =0.001 P_{2-3} =0.004
TP × 1000, ms^2	3.48 (2.81; 4.62)	2.44 (1.78; 5.18)	4.47 (2.61; 6.98)*	P_{1-2} =0.255 P_{1-3} =0.069 P_{2-3} =0.007
SI, units	85.4 (46.6; 119.3)	65.3 (42.2; 181.3)	70.5 (47.3; 132.7)	P_{1-2} =0.147 P_{1-3} =0.733 P_{2-3} =0.035
LF × 1000, ms^2	1.20 (0.97; 1.44)	0.96 (0.55; 1.59)	2.16 (0.94; 4.62)**	P_{1-2} =0.277 P_{1-3} =0.040 P_{2-3} =0.003
LFmx, ms^2/Hz	49.8 (36.4; 59.4)	39.1 (21.0; 53.5)	97.9 (32.5; 247.6)*	P_{1-2} =0.501 P_{1-3} =0.069 P_{2-3} =0.019
LFperiod, sec	12.0 (9.0; 17.4)	13.7 (9.4; 20.1)	9.4 (8.1; 10.9)	P_{1-2} =0.641 P_{1-3} =0.060 P_{2-3} =0.046

**- P<0.05 and ** - P<0.01 between groups*

Compared with the control group, the TP index was also significantly higher (4.47 [2.61;6.98] ×1000, ms^2 versus 2.08 [1.28;2.64] × 1000, ms^2 with $P<0.05$). At the same time, the SI parameter, reflecting sympathetic activation, tended to decrease but statistically remained stable in the dynamics ($P>0.05$) both in the control group and the HRV-BF group. This emphasizes the physiological significance of the LF band, which reflects the complex influence of vagal and sympathetic mechanisms on the heart rhythm. At the same time, with slow breathing, LF is not considered an indicator reflecting sympathetic activity.[12] The period of the dominant (maximum) peak in the LF spectrum (LFperiod) in both groups averaged 9.4 seconds (0.108 Hz). In the HRV-BF group, in recovery stage, we found an increase in the LF band (2.16 [0.94;4.62] × 1000, ms^2 versus 0.75 [0.47;0.92] × 1000, ms^2 in the control group, $P<0.01$) and spectral power of the maximum LF peak (LFmx) (97.9 [32.5;247.6] ms^2/Hz versus 33.5 [23.6;46.1] ms^2/Hz in the control group, $P<0.05$).

In the control group, at the recovery stage (spontaneous breathing), no significant correlations were found between BP and HRV ($P>0.05$). In the HRV-BF group, at the same stage, SBP negatively correlated with LF (r_s=-0.63, P=0.006) and LFmx (r_s= -0.61, P=0.009).

Discussion

The decrease in BP at the recovery stage in the HRV-BF group after its increase during physical exertion in the cold correlates with the spectral power of the HRV LF band and is not associated with the period of the maximum peak of LF, which is related to the respiratory rate. It should be noted that the revealed dominant period at the recovery stage was not only in the LF band but also in the whole HRV spectrum in the HRV-BF group. With preserved cardiorespiratory coupling, the period of the maximum peak in the HRV spectrum reflects the dominant respiration rate. The interquartile ranges of LFperiod in the control and HRV-BF groups at the recovery stage were comparable: 9.4(9.2-9.8) and 9.4(8.1-10.9) seconds, respectively. This corresponds to the preferential respiratory rate range: 6.1-6.5 and 5.5-7.4 respiratory cycles per minute (1/LFperiod), respectively. That is, the optimal breathing rate during biofeedback training after exercise in the cold that will elicit the greatest resonance with respect to sinus arrhythmia may have quite pronounced interindividual variation in the sample, not just around 0.1 Hz (6 respiratory cycles per minute).

Studies devoted to the methodology of HRV-BF training[4,5] also note differences between HRV resonance frequencies and respiratory frequencies during effective HRV-BF training. The spectral power corresponding to the dominant peak of HRV (LFmx) appears to be related to the depth of breathing, making respiratory arrhythmia more pronounced.

In general, HRV-BF training contributes to a significant reduction in BP, especially in subsequent multiple courses of its implementation.[16] Applying such a biofeedback method is also significant for optimizing vascular tone in young residents of the Arctic region, who have more pronounced sympathicotonia and higher BP than in southern geographic latitudes.[17]

The limitations of this study are related to the small sample size and difficulties in selecting individuals with baseline HRV and blood pressure parameters for the study groups among adolescents who have extremely unstable autonomic backgrounds, as well as a lack of time in school physical activity classes that do not allow for more time-consuming biofeedback training. Nevertheless, even such short-term sessions of HRV-BF training can be used in preparation for sports competitions in open cold conditions to prevent cold arterial hypertension. In the prospect of further research, it is necessary to study in more detail spirographic parameters, which will supplement information about the mechanisms of changes in lung ventilation, the degree of pulmonary vasoconstriction during exposure to cold air, which may affect the frequency and depth of breathing during this biofeedback training. Developing optimal breathing patterns to enhance vagal activity further could improve the effectiveness of biofeedback-assisted training by increasing overall HRV following cold-weather exercise.

Conclusion

Short-term HRV-BF training to enhance the overall HRV after exercise in the cold provides a more pronounced reduction in post-load elevated SBP than in the group without this training, against the background of an increase in the HRV LF band and spectral power of the maximum peak of the LF band.

Competing Interests

The author declares that they have no competing interests.

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Ethical Considerations

The research was approved by the Ethical Committee of N. Laverov Federal Center for Integrated Arctic Research of the Ural Branch of RAS (Protocol No. 1, 01.15.2019) and performed in accordance with the ethical principles of the World Medical Association Declaration of Helsinki.

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