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Regional Specificity of Neurovegetative Regulation on the Example of the North-East of Russia and the North Caucasus

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ABSTRACT

BACKGROUND: Heart rate variability (HRV) is a highly informative marker of neurovegetative regulation of cardiovascular activity, as well as a method for quantitatively assessing its physiological changes, allowing for the analysis of the specifics of neurovegetative regulation, taking into account the influence of climatic and geographic factors of different regions of residence.
AIM: The study of regional characteristics, as well as differences in the autonomic control of the circulatory system based on heart rate variability indicators in individuals living in different natural and climatic zones such as the North-East (Magadan) and the North Caucasus (Vladikavkaz), which differ in both climatic conditions and relief (lowland and low mountain).
METHODS: The indices of the autonomic regulation of the heart were assessed in the time and frequency domains in 89 young men, 41 of whom were born in the North-Eastern region (Magadan) (mean age 19.8±0.5 years) and 48 young men were born in the North Caucasus (Vladikavkaz) with an average age of 20.8±0.8 years. All study participants underwent an analysis of the key parameters of the HRV at rest (sitting position) using the «Varicard» hardware and software complex. The type of autonomic regulation was determined based on the variation range (MxDMn) and stress index (SI), assessed in a state of rest.
RESULTS: The results obtained allowed us to establish that living in low-altitude conditions leads to a decrease in vegetative functions, which was associated with a decrease in the activity of the parasympathetic link of the autonomic nervous system, shifting the sympathovagal balance to a relative state of sympathetic activity. In the natives of the North-Eastern region, in lowland conditions, most of the heart rate variability parameters corresponded to the optimal physiological ranges with a shift of a number of parameters to the area of parasympathetic activity.
CONCLUSION: The conducted studies demonstrate that the heart rate variability parameters reflect the specificity of adaptive restructuring of physiological systems, forming ranges of the functional norm characteristic of each natural and climatic zone. These indicators can serve as objective markers of the body's response to extreme environmental factors characteristic of various regions of the Russian Federation. Our study complements the results of scientific research on the shift of the neurovegetative regulation vector to the area of sympathetic activation of the circulatory system as a component of adaptation to combined mountain climatic factors (North Caucasus) and, conversely, in the formation of compensatory mechanisms of vegetative regulation in conditions of extreme climatic factors of the northern territories, manifested in increased tonic activity of the vagus nerve.

Keywords: heart rate variability; climatic and geographic factors; low-altitude conditions; lowland conditions.

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Региональная специфика нейровегетативной регуляции на примере Северо-Востока России и Северного Кавказа

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АННОТАЦИЯ

Обоснование. Вариабельность сердечного ритма представляет собой высокоинформативный маркер нейровегетативной регуляции сердечно-сосудистой деятельности, а также метод количественной оценки её физиологических изменений, позволяющий анализировать специфику нейровегетативной регуляции, в том числе с учётом влияния климатогеографических факторов различных регионов проживания.

Цель. Изучение региональных особенностей, а также различий в вегетативном контроле системы кровообращения на основе показателей вариабельности сердечного ритма у лиц, проживающих в природно-климатических зонах Северо-Востока России (Магадан) и Северного Кавказа (Владикавказ), которые отличаются как по климатическим условиям, так и по рельефу (низменность и низкогорье).

Материалы и методы. Оценивали показатели вегетативной регуляции сердца во временно́й и частотной областях у 89 юношей, из которых 41 — уроженцы Северо-Восточного региона (Магадан; средний возраст 19,8±0,5 года) и 48 — уроженцы Северного Кавказа (Владикавказ; средний возраст 20,8±0,8 года). У всех участников анализировали ключевые параметры вариабельности сердечного ритма в состоянии покоя (положение сидя) с использованием аппаратно-программного комплекса «Варикард». Тип вегетативной регуляции определяли на основании вариационного размаха и индекса напряжения, оцениваемых в состоянии покоя.

Результаты. Полученные результаты позволили установить, что проживание в условиях низкогорья характеризуется снижением вегетативных функций, что связано с уменьшением активности парасимпатического звена вегетативной нервной системы, смещающим симпатовагальный баланс в относительное состояние симпатической активности. У уроженцев Северо-Восточного региона в условиях низменности большинство параметров вариабельности сердечного ритма соответствовали оптимальным физиологическим диапазонам со смещением ряда параметров в область парасимпатической активности.

Заключение. Проведённые исследования демонстрируют, что параметры вариабельности сердечного ритма отражают региональную специфику нейровегетативной регуляции, формируя характерные для каждой природно-климатической зоны диапазоны функциональной нормы. Эти показатели могут служить объективными маркерами реакции организма на экстремальные экологические факторы, характерные для различных регионов Российской Федерации. Наше исследование дополняет научные данные о смещении вектора нейровегетативной регуляции в область симпатической активации системы кровообращения как компонента адаптации к комбинированным горно-климатическим факторам (Северный Кавказ) и, напротив, формирования компенсаторных механизмов вегетативной регуляции в условиях экстремальных климатических факторов северных территорий, проявляющихся в усилении тонической активности блуждающего нерва.

Ключевые слова: вариабельность сердечного ритма; климатогеографические факторы; низкогорье; низменность.

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以俄罗斯东北部与北高加索地区为例，探讨神经植物性调节的区域特性

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摘要

论证。心率变异性是评估心血管自主神经调节功能的高度信息性指标，也是量化其生理变化的有效方法，可用于分析神经植物性调节的区域差异，尤其是在考虑不同地区气候和地理因素影响的背景下。

目的。基于心率变异性指标，研究居住在俄罗斯东北部（Magadan）和北高加索（Vladikavkaz）两个在气候条件与地形类型（低地与低山区）方面存在差异的自然气候区域人群，其心血管系统自主神经调节的区域特征及差异。

材料与方法。对89名青年男性的自主神经调节功能进行评估，其中41人为俄罗斯东北部（Magadan）本地居民（平均年龄19.8±0.5岁），48人为北高加索（Vladikavkaz）本地居民（平均年龄20.8±0.8岁）。在所有受试者中，使用“Varicard”硬件-软件系统，在静息状态（坐位）下测量心率变异性的关键参数。基于静息状态下的变异范围（MxDMn）和应激指数（SI）判断自主神经调节类型。

结果。结果表明，生活在低山区的受试者表现出自主神经功能降低的趋势，主要体现为副交感神经活动下降，植物神经平衡向交感神经激活方向偏移。而东北地区低地居民的心率变异性大多数指标处于最佳生理范围，部分参数呈现出向副交感神经主导方向的偏移。

结论。本研究表明，心率变异性指标可反映自主神经调节的区域特性，形成各自自然气候区的功能性生理参考范围。这些参数可作为机体对俄罗斯不同地区极端环境因子的客观反应标志。我们的研究进一步补充了关于神经自主调节方向偏移的科学资料：在心血管系统中，该偏移表现为向交感神经激活方向移动，作为对复合型山地气候因素（北高加索）的适应性组成部分；相反，在俄罗斯北部地区的极端气候条件下，则形成了以增强迷走神经张力为特征的自主神经调节补偿机制。

关键词：心率变异性；气候地理因素；低山区；低地。

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BACKGROUND

Today, analysis of heart rate variability (HRV) is one of the most popular methods worldwide for studying and evaluating heart function, the functional performance of the body as a whole and the condition of various parts of the autonomic nervous system (ANS) [1]. HRV, which is a change in the time intervals between consecutive heart beats [2], is widely known as an effective tool for assessing the autonomic regulation of the heart [3, 4]. The conventional interpretation of HRV includes an analysis of the parasympathetic and sympathetic activity of the ANS, their balance, and relationship and analysis of some other related parameters [5]. HRV can be used as a health index and a measure of the integration of the ANS and the central nervous system [6, 7]. The neurovisceral integration model suggests that higher control levels of vagal cardiac activity are associated with more effective self-regulation of the body in general, including better health [8]. Various HRV parameters are used for in-depth description of the sympathetic-parasympathetic interaction of the ANS in the cardiovascular regulation and control. The level of regulation can be used to characterize the functional abilities of the cardiovascular system and the adaptation abilities of the body. HRV is a highly sensitive indicator of the dynamic change in the autonomic balance in response to exogenous influences, including climatic and geographical factors [9].

In characterizing the climatic and geographical differences of the studied regions, it is worth noting that Magadan (59°34′ N, 150°47′ E) is located in the temperate climate zone within the coastal climatic zone characterized by a combination of marine and monsoon influences. The climate of the northern part of the Northeast region, including most of the Magadan Region, is considered the harshest in the Russian Far East [10]. Average temperature reflects its obvious seasonality (–26.0 °C in January and + 13.4 °C in July).

Vladikavkaz (Republic of North Ossetia-Alania) is located in a temperate climate zone (43°02′ N, 44°39′ E) with orographic moderation due to the proximity of mountain ranges. The average temperature in January is – 1.9 °C and + 20.7 °C in July. In addition to climatic differences, it is worth noting that Vladikavkaz is located in the foothills zone of the Greater Caucasus, in the North Ossetian Trench framed by the offsets of the Sunzhensky and Terskiy Ridges. The terrain is characterized by deep differentiation with absolute marks from 600 to 1,000 m and average height of about 670 m above sea level, which corresponds to low-mountain relief, according to the contemporary geomorphological classification. Magadan is located in the coastal climate zone and characterized by low-lying relief with absolute heights not exceeding 100 m above sea level. Such hypsometric conditions create a specific complex of factors affecting the physiological adaptation of the human body.

AIM: To study regional differences and differences in the autonomic control of the circulatory system based on HRV in individuals living in different climate zones, such as the Northeast (Magadan) and the North Caucasus (Vladikavkaz), which differ in both climatic conditions and relief (lowland and low mountain).

METHODS

The study involved 89 young men, including 41 natives of the Northeast region (Magadan; mean age: 19.8 ± 0.5 years) and 48 natives of the North Caucasus (Vladikavkaz; mean age: 20.8±0.8 years). The study was conducted in the spring (April, May) of 2024.

Inclusion criteria: males in their young adulthood; no acute chronic diseases and health complaints, and a signed informed consent. All participants included in the sample had comparable living conditions (students) and physical activity (physical education classes as part of the educational institution's curriculum) and permanently resided in the studied region.

All study participants underwent an analysis of HRV using the Varicard suite and VARICARD-KARDi and ISCIM-6 software. The subjects had the following HRV parameters recorded in the time and frequency domains: heart rate (HR, bpm); mode (Mo, ms); difference between maximum and minimum RR intervals, or variation range (MxDMn, ms); root mean square of successive differences (RMSSD, ms); standard deviations of all NN intervals (SDNN, ms); stress index (regulatory stress index; SI, relative units); total power (TP, ms^2); total high-frequency (HF) HRV in the range of 0.4–0.15 Hz (respiratory waveforms; HF, ms^2); low-frequency (LF) HRV in the range of 0.15–0.04 Hz (vascular waveforms; LF, ms^2), very low-frequency (VLF) HRV in the range of 0.04–0.015 Hz (VLF, ms^2). In addition, we analyzed the centralization index (IC, relative units [RU]) and the activity index of regulatory systems (IARS, RU) [11]. The subjects' type of autonomic regulation was determined based on the variation range (MxDMn) and stress index (SI) at rest. Normotonic individuals included participants with MxDMn in the range of 200–300 ms and SI of 70–140 RUs; sympathotonic individuals included participants with MxDMn below the specified range and SI higher than 140 RUs; vagotonic individuals included participants with MxDMn above the specified range and SI less than 70 RUs [12].

The study was approved by the Ethics Committees of the Institute of Biomedical Research, a branch of the Federal State Budgetary Scientific Institution Vladikavkaz Scientific Center of the Russian Academy of Sciences (protocol No. 3 dated February 20, 2022), and the Federal State Budgetary Scientific Institution Arctic Research Center of the Far Eastern Branch of the Russian Academy of Sciences (Opinion No. 002/021 dated November 26, 2021).

Statistical data processing was performed by standard methods of mathematical statistics in the Statistica 7.0 software. To test the normality of the quantitative variables, we used the Shapiro–Wilk and Kolmogorov–Smirnov tests. The analyzed variables are presented as median (Me) and

interquartile range [q25%; q75%]. The significance of differences in the analyzed variables was determined using the Mann–Whitney U test. The difference was considered significant at p=0.05; 0.01; 0.001.

RESULTS

The study involved a comprehensive analysis of autonomic cardiovascular regulation based on the HRV time and frequency domains in groups of young men from different regions, including northeast Russia (Magadan) and the North Caucasus (Vladikavkaz, Republic of North Ossetia-Alania). The distribution of types of autonomic heart rate regulation in young men living in different environment and climate with significant gradients of meteorological parameters and altitude above sea level is shown in Fig. 1. It is evident that among natives of the northeast, the share of vagotonic individuals is 59.0%, the share of normotonic individuals is 27.0%, and the share of sympathotonic individuals is 14.0%. On the contrary, the share of vagotonic individuals among natives of the North Caucasus is 20.8%, the share of normotonic

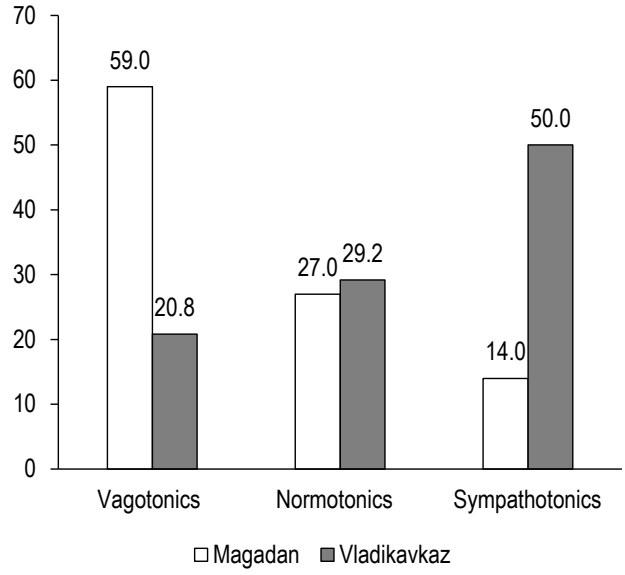

Fig. 1. Distribution of types of vegetative regulation HR in young men, living in different natural and climatic zones: the North-East (Magadan) and the North Caucasus (Vladikavkaz).

Table 1. Main indicators of heart rate variability and the level of significance of their differences in young men depending on the climatic and geographical conditions of residence

Parameters	Me (q25; q75)		p
	Magadan Region (n=41)	Republic of North Ossetia-Alania (n=48)	
HR, beats/min	74.72 (65.21; 84.38)	85.20 (76.34; 93.48)	0.001
MxDMn, msec	255.00 (203.00; 366.00)	231.00 (182.00; 301.00)	0.114
RMSSD, msec	40.58 (29.73; 64.11)	34.17 (23.36; 49.69)	0.043
pNN50, %	13.58 (7.09; 35.63)	8.35 (2.63; 19.47)	0.020
SDNN, msec	49.20 (38.70; 70.92)	51.33 (41.12; 65.50)	0.955
Mo, msec	808.00 (707.00; 905.00)	688.00 (635.00; 747.00)	0.001
AMo50, msec	43.23 (26.02; 52.66)	49.57 (34.60; 58.95)	0.083
SI, arb. units	112.21 (38.77; 165.33)	139.70 (70.46; 232.35)	0.053
TP, msec^2	2481.76 (1510.57; 4874.63)	2107.10 (987.70; 3075.40)	0.050
HF, msec^2	730.25 (401.88; 1348.17)	526.47 (253.84; 844.77)	0.050
LF, msec^2	1151.12 (729.14; 2112.35)	1007.59 (582.80; 1656.63)	0.202
VLF, msec^2	411.46 (255.11; 926.64)	336.36 (149.52; 625.370	0.105
LF/HF, arb. units	1.68 (1.15; 2.61)	1.94 (1.19; 3.02)	0.429
IC, arb. units	2.44 (1.72; 3.50)	2.82 (1.61; 4.02)	0.524
PARS, arb. units	4.00 (3.00; 6.00)	5.00 (4.00; 7.00)	0.135

Note. HR is the heart rate; MxDMn is the difference between the maximum and minimum values of the cardiointervals, or the variation range; RMSSD is the square root of the sum of the differences in a consecutive series of cardiointervals; pNN50 is the number of pairs of cardiointervals with a difference of more than 50 ms, % of the total number of cardiointervals; SDNN is the standard deviation of the full array of cardiointervals; Mo is the mode; AMo is the amplitude of the mode; SI is the stress index (voltage index of regulatory systems); TP is the total power of the spectrum of time values of R-R heart rate intervals.; HF is the spectral power of the high–frequency component of heart rate variability in the range of 0.4–0.15 Hz (respiratory waves); LF is the spectral power of the low–frequency component of heart rate variability in the range of 0.15–0.04 Hz (vascular waves); VLF is the spectral power of the very low–frequency component of heart rate variability in the range of 0.04-0.015 Hz;. LF/HF is an indicator of sympathovagal balance; IC is an index of centralization, PARS is an indicator of the activity of regulatory systems; p is the level of statistical significance.

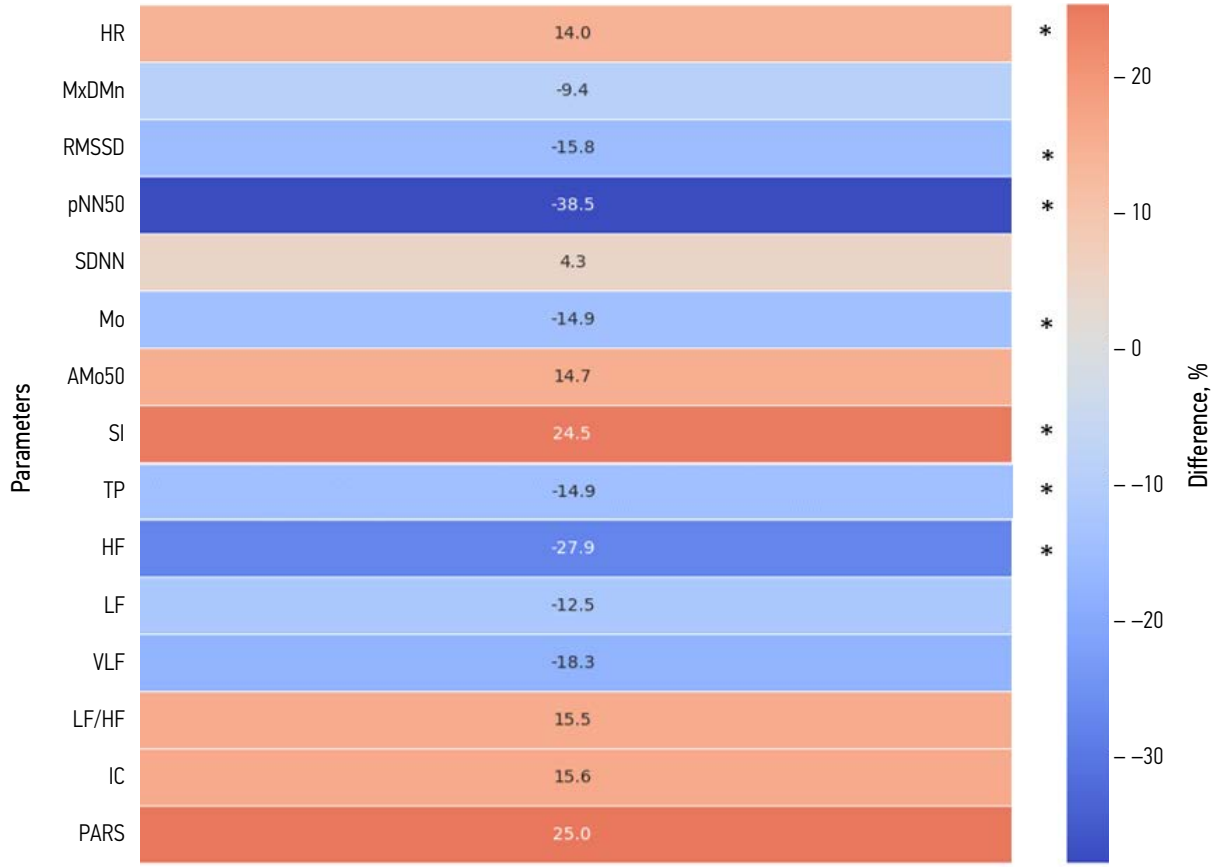

Fig. 2. Intergroup differences in heart rate variability in young men of the North Caucasus and North-Eastern regions of Russia. * Statistically significant intergroup differences are indicated. Blue color range — the value is higher for representatives of the north-eastern region, red color range — the value is higher for representatives of the North Caucasus.

individuals is 29.2%, and the share of sympathotonic individuals is 50.0%.

The basic HRV parameters and significance of differences between groups in the samples of young men living in different climate and geographic zones of the Russian Federation are shown in Table 1. The study shows that in 15 analyzed HRV parameters, we observed significant differences between groups in seven parameters as clearly shown in Fig. 2.

It was found that the group of young men from the northeast Russia had significantly higher RMSSD (p=0.043), pNN50 (p=0.020), and Mo (p=0.001) backed by lower SI (p=0.053) and HR (p=0.001).

An analysis of the HRV frequency between the study groups showed that the total power (TP), reflecting the total activity of the body's regulatory systems, was lower in the group of young men from the North Caucasus due to a lower HF HRV (p=0.050).

DISCUSSION

The intragroup analysis of the types of autonomic heart rate regulation shows the proportional distribution of individuals with different types of regulation. This analysis clearly demonstrates the intergroup differences, namely the predominant sympathotonic type of HRV in young male natives of the North Caucasus (Vladikavkaz), parasympathetic type of HRV in natives of the northeast Russia (Magadan), thereby reflecting the population levels of rhythm variability in the studied age and sex groups. Analysis of the obtained data showed significant differences between both groups in some key HRV parameters (HR, Mo, RMSSD, pNN50, SI, HF, and TP). The study reveals a predominant parasympathetic type of cardiac activity control in the northeastern population compared to residents of the North Caucasus Region. For example, participants from the Northeast region tended to have a greater heart rate variability (TP) with a higher median RMSSD and pNN50, which together indicate the predominance of parasympathetic type of the ANS regulation. It is known that at physiological rest, predominantly parasympathetic activity provides the optimum economization of the body's functions and bioenergetic processes. An inverse relationship is observed with initial sympathicotonia: increased tone of the sympathetic ANS correlates with functional physiological stress and lower adaptation abilities, limiting the range of possible compensatory reactions when exposed to disturbing factors [13].

It has been shown that young natives of the Republic of North Ossetia-Alania have a significant predominance of HR, IC, SI, and IARS. The data reveal a pronounced vagal dominance in relation to the reduced sympathetic modulation observed with a relatively increased overall heart rate variability

in young men from the northeast Russia. These differences may be interpreted as population specificity of the autonomic balance under chronic exposure to extreme climatic factors of the northern regions manifested in the activation of parasympathetic cardiac regulation. The findings are consistent with the data on the effect of low temperatures on HRV causing lower sympathetic activity and, consequently, a higher HRV [14]. They are also consistent with our previous studies showing that the identified parasympathetic activation of the ANS improves gas exchange in the context of cardiovascular stress in Northern conditions and may indicate increased cold resistance [15, 16].

The interpretation of IARS values indicates that young men in the Northeast region have moderate regulatory stress; whereas, the North Caucasus sample has a high regulatory stress caused by the active mobilization of the sympathetic (adrenal) system and the pituitary-adrenal system [17–19].

CONCLUSION

The study involved a comprehensive analysis of time and frequency domains of HRV in two groups of young men permanently residing in contrasting climate and geographic zones of the Russian Federation. The findings significantly expand the contemporary understanding of neurovegetative adaptations to various extreme environmental factors. The study demonstrates fundamentally different autonomic control patterns in response to combined mountain climatic factors, manifested by the persistent sympathicotonic dominant and lower parasympathetic activation in autonomic regulation. In the conditions of northeast Russia, the opposite adaptation manifested by a higher overall variability and parasympathetic activation in the autonomic circulatory regulation. The revealed autonomic differences in the vegetative cardiovascular regulation patterns based on climatic and geographic parameters demonstrate the specificity of the autonomic response.

Our data demonstrate the diagnostic value of HRV for monitoring physiological acclimatization and identifying individual characteristics of autonomic regulation in various environments. These observations support the hypothesis that climatic and geographic factors are important for the development of individual autonomic cardiovascular regulation system. The findings require further study to specify the interaction mechanisms of external factors and internal regulatory processes and development of methods to improve public health in various climate zones.

This study has some limitations as it involved young males, which does not allow a full description of the corresponding populations.

ADDITIONAL INFORMATION

Author contributions: V.A. Belyayeva: study concept and design, data analysis, writing and editing the manuscript; I.V. Averyanova: study concept and design, preparation of the first version of the manuscript, literature analysis, approval of the final version of the manuscript. All authors approved the manuscript (the version for publication), and also agreed to be accountable for all aspects of the work, ensuring proper consideration and resolution of questions related to the accuracy and integrity of any part of it.

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Statement of originality: No previously published material (text, images, or data) was used in this work.

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ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. В.А. Беляева — концепция и дизайн исследования, анализ данных, написание и редактирование текста рукописи; И.В. Аверьянова — концепция и дизайн исследования, подготовка первого варианта текста рукописи, анализ литературных данных, утверждение окончательного варианта рукописи. Все авторы одобрили рукопись (версию для публикации), а также согласились нести ответственность за все аспекты работы, гарантируя надлежащее рассмотрение и решение вопросов, связанных с точностью и добросовестностью любой её части.

Этическая экспертиза. Исследование одобрено этическими комитетами Института биомедицинских исследований — филиала Федерального государственного бюджетного учреждения науки Федерального научного центра «Владикавказский научный центр Российской академии наук» (протокол № 3 от 20.02.2022) и Федерального государственного бюджетного учреждения науки «Научно-исследовательский центр «Арктика» Дальневосточного отделения Российской академии наук» (заключение № 002/021 от 26.11.2021).

Согласие на публикацию. Все участники исследования добровольно подписали форму информированного согласия до включения в исследование.

Источники финансирования. Работа выполнена за счёт бюджетного финансирования ИБМИ ВНЦ РАН в рамках темы «Изучение молекулярно-генетических механизмов стрессорных, воспалительных и метаболических нарушений при сердечно-сосудистой и бронхолегочной патологии в эксперименте и клинике в динамике медико-экологического мониторинга в РСО-Алания, разработка технологий профилактики и коррекции (экспериментально-клиническое исследование)» (рег. номер 125030603222-0) и НИЦ «Арктика» ДВО РАН в рамках темы «Изучение межсистемных и внутрисистемных механизмов реакций в формировании функциональных адаптивных резервов организма человека северного типа на разных этапах онтогенеза лиц, проживающих в дискомфортных и экстремальных условиях с определением интегральных информативных индексов здоровья» (рег. номер АААА-А21-121010690002-2).

Раскрытие интересов. Авторы заявляют об отсутствии отношений, деятельности и интересов за последние три года, связанных с третьими лицами (коммерческими и некоммерческими), интересы которых могут быть затронуты содержанием статьи.

Оригинальность. При создании настоящей работы авторы не использовали ранее опубликованные сведения (текст, иллюстрации, данные).

Доступ к данным. Редакционная политика в отношении совместного использования данных к настоящей работе не применима, новые данные не собирали и не создавали.

Генеративный искусственный интеллект. При создании настоящей статьи технологии генеративного искусственного интеллекта не использовали.

Рассмотрение и рецензирование. Настоящая работа подана в журнал в инициативном порядке и рассмотрена по обычной процедуре. В рецензировании участвовали два внешних рецензента, член редакционной коллегии и научный редактор издания.

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