PREVENTIVE MEDICINE

INTERSYSTEM INTERACTIONS OF PHYSIOLOGICAL SYSTEM INDICATORS IN STUDENTS WITH DIFFERENT TYPES OF AUTONOMIC REGULATION

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ABSTRACT

Studying not only individual students indicators of students, but complex intersystem interactions that reflect the specifics of adaptive capabilities is of scientific interest.
The aim of the study. *To reveal the features of intersystem interactions of indicators of the blood vessels functional state, morphological and neurodynamic characteristics of students with different types of autonomic regulation, living in the Khanty-Mansiysk Autonomous Okrug – Yugra.*
Methods. *429 first–fourth-year students (348 girls, 80 boys) of the Surgut State Pedagogical University were examined. The initial type of autonomic regulation was determined by the average duration of electrocardiogram RR intervals. Anthropometry parameters (body length and weight) and body composition were assessed using Tanita BC-601 device (Tanita, Japan), vascular wall elasticity – using AngioScan-01 (AngioScan-Electronics Ltd, Russia), neurodynamic indicators – using NS-PsychoTest device (Neurosoft, Russia). Statistical analysis was carried out using Statistica 7.0 software (StatSoft Inc., USA). We used the nonparametric Mann – Whitney U-test to evaluate differences and the nonparametric Pearson R-test to analyze correlations.*
Results. *An increase in the stiffness of the vascular wall of large and small arteries in girls is accompanied by an increase in parasympathetic activity. In young men, an increase in the stiffness of large arteries raises with an increase in sympathoadrenal activity, while a compensatory increase in the stiffness of small muscular arteries is noted with an increase in parasympathetic activity. In persons with the sympathicotonic type of autonomic regulation, an excess content of fat mass, an increased frequency of visceral obesity, and a deficiency in water content were registered. With the predominance of the parasympathetic component contribution to the regulation of cardiac rhythm, an increase in the processes of inhibition in the central nervous system was noted. In young men, reduced sensorimotor reactions are consistent with sympathetic activation in the regulation of heart rate. Correlation analysis made it possible to establish some features in the interaction of the vascular, morphological and central nervous systems.*
Conclusion. *Differences in indicators of functional systems (physical development, blood flow, neurodynamic characteristics) in the examined groups of students are shown, taking into account gender and autonomic regulation type. Features of intersystem interactions of indicators of physiological systems of students' bodies with different types of autonomic regulation were revealed.*

Key words: *type of neurovegetative regulation, functional state of the vascular system, anthropometry, body composition, neurodynamics, intersystem interactions, students, Northern region*

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ОСОБЕННОСТИ МЕЖСИСТЕМНЫХ ВЗАИМОДЕЙСТВИЙ ПОКАЗАТЕЛЕЙ ФИЗИОЛОГИЧЕСКИХ СИСТЕМ ОРГАНИЗМА СТУДЕНТОВ С РАЗНЫМ ТИПОМ ВЕГЕТАТИВНОЙ РЕГУЛЯЦИИ

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РЕЗЮМЕ

Научный интерес представляет изучение не отдельных показателей организма обучающихся, а комплексных межсистемных взаимодействий, отражающих специфику адаптационных возможностей.

Цель исследования. *Выявить особенности межсистемных взаимодействий показателей функционального состояния сосудов, морфологических и нейродинамических характеристик студентов с разным типом вегетативной регуляции, проживающих в Ханты-Мансийском автономном округе – Югре.*

Методы. *Обследовано 429 студентов 1–4-х курсов (девушки – 348, юноши – 80) БУ «Сургутский государственный педагогический университет». Исходный тип вегетативной регуляции определяли по средней продолжительности RR-интервалов электрокардиограммы. Оценивали показатели антропометрии (длину и массу тела) и компонентного состава тела (прибор Tanita BC-601 (Tanita, Япония)), эластичность сосудистой стенки (прибор «АнгиоСкан-01» (ООО «АнгиоСкан-Электроникс», Россия)); нейродинамические показатели (прибор «НС-ПсихоТест» (Нейрософт, Россия)). Статистический анализ проведён в среде Statistica 7.0 (StatSoft Inc., США). Использовали непараметрический U-критерий Манна – Уитни для оценки различий и непараметрический R-критерий Пирсона для анализа корреляционных связей.*

Результаты. *Увеличение жёсткости сосудистой стенки крупных и мелких артерий у девушек сопровождается ростом парасимпатической активности; у юношей увеличение жёсткости крупных артерий возрастает с увеличением симпатоадреналовой активности, при этом отмечается компенсаторное увеличение жёсткости мелких мышечных артерий с ростом парасимпатической активности. У лиц симпатикотонического типа вегетативной регуляции отмечены избыточное содержание жировой массы и повышенная частота висцерального ожирения, дефицит содержания воды. С преобладанием вклада парасимпатического компонента в регуляцию кардиоритма отмечено увеличение процессов торможения в центральной нервной системе. У юношей сниженные сенсомоторные реакции согласованы с симпатической активацией в регуляции кардиоритма. Корреляционный анализ позволил установить некоторые особенности во взаимодействии сосудистой, морфологической и центральной нервной системы.*

Заключение. *Показаны отличия по показателям функциональных систем (физического развития, сосудистого русла, нейродинамических характеристик) в обследованных группах студентов с учётом пола и типа вегетативной регуляции. Выявлены особенности межсистемных взаимодействий показателей физиологических систем организма студентов с разным типом вегетативной регуляции.*

Ключевые слова: *тип нейровегетативной регуляции, функциональное состояние сосудистой системы, антропометрия, компонентный состав тела, нейродинамика, межсистемные взаимодействия, студенты, Северный регион*

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OBJECTIVES

Modern physiological research is aimed not only at analyzing individual average values of parameters of functional systems, but also at an integrative assessment of the functioning of the body. In this regard, along with the individual components of the systems, it seems relevant to study the interrelationships between them [1]. From our point of view, it is interesting to study the relationship between the functioning of the cardiovascular system and other body systems. Many modern authors single out this system as the most sensitive to unfavorable climatic and ecological factors in the northern territories, including the Khanty-Mansiysk Autonomous Okrug – Yugra [2–4].

Students as a special cohort exposed to a complex of specific social and environmental factors is of special scientific interest [5]. It is known that in modern conditions, studying at a university is associated with a high level of mental and physical stress, which often leads to a strain on the adaptive capabilities of the body of students.

According to E.M. Kazin et al. [6], if a specific functional system does not cope with its task, the functional performance support system is activated, while the costs of functional reserves increase. Having different adaptive potential, students' bodies react differently to external impacts, and as a result, the "cost" of adaptation is determined by the state of the body's regulatory systems, primarily the central nervous system (CNS) and autonomic regulation. The variability of heart rate indicators acts as a universal indicator of the functional state of the multilevel links of the regulatory systems of the human body, they are the first to activate and adapt to environmental factors.

An increasing number of authors are inclined to the need to take into account the type of autonomic regulation in the analysis and interpretation of heart rate variability (HRV) indicators [4, 7, 8]. The establishment of the type of autonomic regulation is extremely important in the individual assessment of HRV parameters and is especially important when choosing the type and intensity of exercise, identifying the risks of developing pathology of the cardiovascular system.

It is known about the influence of the type of autonomic regulation on the functioning of individual systems [9], including in extreme conditions of the Northern territories [10], however, the features of intersystem interactions of the functional state of blood vessels, morphological and neurodynamic parameters of students with different types of autonomic regulation have not been sufficiently studied [11]. Recent publications [3, 4, 9–11] indicate the influence of many factors (the level and duration of stress influences, the season of the year, gender and age, type of professional and educational activities, etc.) on the nature and strength of intersystem interactions. In this regard, we believe it is relevant to identify the features of intersystem interactions in students living in the conditions of the northern region.

THE AIM OF THE STUDY

To reveal the features of intersystem interactions of functional state of arterial vessels, morphological and neurodynamic characteristics of students with different types of autonomic regulation, living in the Khanty-Mansiysk Autonomous Okrug – Yugra.

MATERIALS AND METHODS

The examination was carried out on the basis of the Scientific Laboratory "Biological Foundations of Educational Safety", Surgut State Pedagogical University. A total of 429 first–fourth-year students aged 17–21 years were examined. All the examined students were representatives of non-indigenous nationalities. They were born and permanently (or more than 10 years) reside on the territory of the Khanty-Mansiysk Autonomous Okrug – Yugra (a territory equalled to the conditions of the Far North).

The total sample is differentiated by gender and type of autonomic regulation: girls (n = 348) – sympathotonics (n = 107), normotonics (n = 210) and vagotonics (n = 31); boys (n = 80) – sympathotonics (n = 8), normotonics (n = 49), vagotonics (n = 23). The study included only those girls who were in the follicular phase of the menstrual cycle. The exclusion criteria were acute infectious diseases or exacerbation of chronic pathology.

The initial type of autonomic regulation was determined by the electrocardiogram (ECG) indicator – the average duration of RR intervals (RRNN). ECG recording was performed under standardized conditions in a supine position (5 min), with calm breathing, in the second standard lead. HRV recordings different from sinus rhythm were excluded from the analysis. The normotonic type corresponded to the range of RRNN values of 750–980 ms (60–80 bpm), RRNN values above this range characterize the parasympathetic type, below this range – sympathicotonic type of autonomic regulation.

The functional state of the vascular system was assessed by the level of blood pressure (BP) measured using a standard technique using an electronic tonometer from A&D Medical (Japan), model – UA-777, and the following parameters were recorded: SBP – systolic blood pressure (mmHg); DBP – diastolic blood pressure (mmHg). To assess the elasticity of the arterial vascular wall, the AngioScan-01 diagnostic complex (AngioScan-Electronics LLC, Russia; certificate of conformity No. РОСС RU.ИМ25.Д06096) was used: according to the photoplesiogram, the stiffness index (SI, m/s) was analyzed, reflecting the average velocity of pulse waves propagation through the aorta and its branches; reflection index (RI, standard units), characterizing the tone of small muscular arteries; augmentation index, standardized for a fixed pulse rate of 75 bpm (AIp75, %); pressure gain indicator, depending on the total peripheral vascular resistance and elastic resistance of the vascular wall; aging index (AGI, standard units), evaluating the shapes of pulse waves of volume; ejection duration

in the cardiac cycle (ED, ms); stress index (standard units), characterizing heart rate variability.

Absolute anthropometric parameters – length (cm) and body weight (BW; kg) – were measured using standardized methods, using a medical stadiometer and scales. Next, the body mass index (BMI; kg/m^2) was calculated. The assessment of body composition: body fat mass (FM; %), visceral fat (VF; standard units) and body water percentage (BWP; %), was carried out using Tanita BC-601, body composition analyzer scales (Tanita, Japan; certificate of conformity No. POCC JP.ME77.B08130) in modification for screening purposes.

The study of neurodynamic parameters was carried out using NS-Psychotest hardware and software complex (NeuroSoft, Russia; certificate of conformity No. POCC RU. *И*М18.Д00567) according to the following methods: "Simple visual-motor reaction" (SVMR; ms), reflecting the speed of sensorimotor response to a similar stimulus and the level of CNS activation; "Complex visual-motor reaction (choice reaction)" (CVMR, ms), characterizing the mobility of nervous processes and the level of differentiating inhibition; "Tap test", diagnosing the strength of nerve processes. Along with this, the values of the standard deviation (SD) of the SVMR and CVMR (SVMR SD and CVMR SD) reflecting the stability of the sensorimotor response were recorded.

The statistical analysis of the results was carried out using the Statistica 7.0 application software package (StatSoft Inc., USA). A descriptive statistical analysis of the data was performed. The assessment of the normality of the distribution of the studied indicators was carried out using the Shapiro – Wilk test. Some quantitative features did not correspond to the law of normal distribution, so these results are presented in the form of median (Me) and interquartile range – the 25th and 75th percentiles (Q_{25}; Q_{75}). The differences were analyzed using the nonparametric Mann – Whitney U-test by pairwise comparison of the studied groups. Nonparametric Spearman's test was used to evaluate correlations. The critical level of statistical significance was $p < 0.017$ for all calculations.

The study was carried out during the intersessional period.

Ethical review

The fundamental principle of the study was the absence of risk to the health of students, compliance with humane and ethical standards that meet the requirements of the World Medical Association Declaration of Helsinki (ed. 2013). Written informed consent was obtained from each participant of the study before performing the procedures. The study protocol was approved by the Bioethics Committee of the Surgut State Pedagogical University (Protocol No. 31 dated September 7, 2022).

RESULTS

The average values of indicators characterizing the state of the cardiovascular system (AD, SI, AIp75, RI, AGI) indicate the optimal functional state of the examined students of both genders. The results obtained, taking into account gender and type of autonomic regulation, are presented in Table 1.

The blood pressure indicators of young men and women corresponded to the age norm. The value of SI (m/s) in young men exceeded the values of this indicator in young women, which indicates a more pronounced decrease in the elasticity of large resistive arterial vessels in male students. The value of AIp75 (%), characterizing the elasticity of large-caliber arterial vessels, showed a different connection with the type of autonomic regulation: in young women, it was the largest in the group of sympathicotonics, the smallest in the group of vagotonics, and in young men, on the contrary. Indicators of elasticity of small arteries (RI, standard units) in young women showed a statistically significant increase from the sympathicotonic group to the vagotonic group; in young men, the same trend was found, but not statistically confirmed. In young men, the average augmentation index decreased from the group of sympathotonics to vagotonics, which have the most optimal average index of elasticity of large arteries. The values of the aging index (AGI, standard units) are due to changes in blood pressure and heart rate (HR). The established values of this indicator fell within the range of reference values (–0.93 ± 0.25) for all study groups. Statistically significant differences in the values of AIp75, RI and AGI in young men have not been established. The average stress index in the groups of young men and women with pronounced sympathicotonia was statistically significantly higher than this indicator in the groups of normotonics and vagotonics (2 and 4 times, respectively), which indicates a pronounced stress-induced fatigue of the body of these students.

The features of neurovegetative regulation determine the nature of adaptive reactions of the body, which is reflected, among other things, on metabolic parameters. The indicators of morphological development of students with different types of autonomic regulation are presented in Table 2.

It was found that in young men and women with pronounced sympathicotonia body weight (kg) and fat mass (%) indicators were higher than the values of similar indicators in other groups. Statistically significant intersex differences between the normotonic groups were found by BMI (kg/m^2). An increase in BWP (%) was noted in young men and women of the examination groups from sympathotonics to vagotonics.

Generalized characteristics of neurodynamic characteristics of students with different types of autonomic regulation are presented in Table 3.

A decrease in sensorimotor activity was found in young women with an increase in vagal tonic activity, which is reflected in an increase in the average reaction time. The results obtained characterize a decrease in the speed of processing sensory information and the formation of a motor response to a stimulus, lower mobility and CNS excitability of vagotonic girls compared with sympathiconics (on average by 4–7 %). Among the examined young men, the optimal type of sensorimo-

TABLE 1

INDICATORS OF THE ARTERIAL WALLS IN STUDENTS WITH DIFFERENT TYPES OF AUTONOMIC REGULATION, ME (Q_{25}; Q_{75})

Indicators	Gender	Type of autonomic regulation			*P*
		sympathicotonia	normotonia	vagotonia	
SBP, mmHg	♀	111.0 (105.0; 121.0)	108.0 (101.0; 115.0)	110.0 (103.0; 117.0)	$p_1 = 0.003$
	♂	117.0 (110.0; 124.0)	118.0 (110.0; 124.0)	119.0 (108.0; 125.0)	–
*p**		–	< 0.001	0.01	
DBP, mmHg	♀	72.0 (67.0; 79.0)	70.0 (64.0; 75.0)	65.0 (60.0; 70.0)	$p_1 < 0.001$ $p_2 = 0.003$ $p_3 < 0.001$
	♂	72.5 (66.0; 76.0)	75.0 (70.0; 80.0)	71.0 (66.0; 74.0)	$p_2 < 0.001$
*p**		–	< 0.001	0.006	
SI, m/s	♀	7.2 (6.8; 7.7)	7.0 (6.7; 7.4)	6.9 (6.5; 7.7)	–
	♂	7.3 (7.0; 8.0)	7.5 (6.8; 7.8)	7.5 (7.0; 7.7)	–
*p**		–	< 0.001	–	
AIp75, %	♀	–12.0 (–17.3; –3.4)	–11.4 (–18.8; –5.3)	–3.7 (–11.7; –1.0)	$p_1 < 0.001$ $p_2 < 0.001$ $p_3 < 0.001$
	♂	–17.0 (–22.3; –11.7)	–18.6 (–23.2; –6.1)	–25.7 (–35.9; –15.7)	–
*p**		–	0.009	< 0.001	
AGI, standard units	♀	–0.9 (–1.1; –0.8)	–0.9 (–1.0; –0.8)	–0.8 (–1.0; –0.6)	–
	♂	–1.1 (–1.2; –1.0)	–0.8 (–1.1; –0.9)	–1.0 (–1.2; –0.9)	–
*p**		–	–	0.003	
RI, standard units	♀	19.3 (14.4; 24.8)	26.2 (19.8; 32.1)	34.1 (24.1; 41.3)	$p_1 < 0.001$ $p_2 = 0.003$ $p_3 < 0.001$
	♂	16.1 (13.7; 21.8)	20.2 (14.2; 23.4)	23.5 (20.5; 30.3)	–
*p**		–	< 0.001	0.01	
ED, ms	♀	263.0 (250.0; 275.0)	274.0 (262.0; 288.0)	287.0 (268.0; 300.0)	$p_1 < 0.001$ $p_3 < 0.001$
	♂	270.0 (243.0; 282.5)	264.0 (251.0; 272.0)	276.0 (268.0; 288.0)	$p_2 < 0.001$
*p**		–	< 0.001	–	
Stress index, standard units	♀	206.0 (132.0; 337.0)	96.0 (63.0; 180.0)	46.0 (31.0; 75.0)	$p_1 < 0.001$ $p_2 < 0.001$ $p_3 < 0.001$
	♂	235.0 (179.5; 362.5)	125.0 (83.0; 182.0)	49.0 (30.0; 87.0)	$p_2 < 0.001$
*p**		-	–	–	

Note. ♀ – women; ♂ – men; statistically significant differences between groups: p_1 – sympathicotonics and normotonics; p_2 – normotonics and vagotonics; p_3 – sympathicotonics and vagotonics; *p** – statistically significant differences between genders.

TABLE 2

INDICATORS OF MORPHOLOGICAL DEVELOPMENT OF STUDENTS WITH DIFFERENT TYPES OF AUTONOMIC REGULATION, ME (Q_{25}; Q_{75})

Indicators	Gender	Type of autonomic regulation			*p*
		sympathicotonia	normotonia	vagotonia	
BMI, kg/m^2	♀	21.9 (19.2; 26.1)	21.8 (20.0; 24.3)	20.2 (19.3; 22.6)	–
	♂	22.7 (21.2; 26.3)	23.1 (20.9; 26.3)	23.0 (21.5; 24.7)	–
*p**		–	0.008	–	
BW, kg	♀	61.0 (50.9; 69.4)	59.5 (53.0; 66.4)	56.2 (52.0; 65.0)	–
	♂	75.2 (60.7; 82.8)	73.0 (65.9; 80.5)	73.4 (63.6; 77.0)	–
*p**		0.01	< 0.001	< 0.001	
FM, %	♀	28.1 (21.1; 36.2)	27.8 (22.7; 33.1)	26.2 (21.4; 29.8)	–
	♂	26.1 (17.3; 35.0)	16.5 (11.8; 21.2)	16.3 (13.2; 19.2)	–
*p**		–	< 0.001	< 0.001	
BWP, %	♀	53.3 (47.7; 58.4)	53.6 (49.8; 57.1)	54.9 (52.3; 58.0)	–
	♂	54.2* (48.0; 61.1)	60.9 (56.5; 66.0)	63.4 (59.1; 66.8)	$p_3 = 0.01$
*p**		–	< 0.001	< 0.001	
VF, standard units	♀	1.0 (1.0; 4.0)	1.0 (1.0; 3.0)	1.0 (1.0; 2.0)	–
	♂	3.5 (1.5; 5.5)	1.0 (1.0; 4.0)	1.0 (1.0; 2.0)	–
*p**		–	–	–	

Note. ♀ – women; ♂ – men; statistically significant differences between groups: p_1 – sympathicotonics and normotonics; p_2 – normotonics and vagotonics; p_3 – sympathicotonics and vagotonics; *p** – statistically significant differences between genders.

tor response was revealed in normotonics, while the indicators of sympathicotonics and vagotonics had similar severity. It is important to note that the variability indicators (SVMR SD and CVMR SD), reflecting the homeostatic level of sensorimotor response, corresponded to the range of normative values in all study groups. In the groups of examined young women, we did not find a statistically significant effect of the type of autonomic regulation on the performance of the motor component of activity (according to the tap test). In young men, optimal indicators were noted in normotonics, while sympathicotonics and vagotonics found similar manifestations of sensorimotor performance. Statistically significant differences between genders in most of the analyzed characteristics were revealed in the group of normotonics. In general, the most adequate indicators of sensorimotor response of normotonic young men can be noted in comparison with other studied groups.

In physiology, the principle is increasingly being introduced, the meaning of which is that the optimal result of the system's performance under the same type of conditions is achieved by a variety of states that are characterized by certain quantitative combinations of parameters. One of the ways to characterize physiological systems can be a correlation analysis to identify the structure of the connection between individual indicators in various adaptive states [12]. The results of our correlation intersystem analysis of groups of students with different types of vegetative response indicate pronounced differences between them. The correlation matrix uniting students of both genders is presented in Table 4, it reflects statistically significant connections between the indicators.

According to the classical concepts of systemic physiology of I.I. Schmalthausen, R. Settler, generalized in the work of A.A. Pozdnyakova [13], a living organism is considered as a complex hierarchically subordinated dynamic struc-

TABLE 3

NEURODYNAMIC INDICATORS OF STUDENTS WITH DIFFERENT TYPES OF AUTONOMIC REGULATION, ME (Q_{25}; Q_{75})

Indicators	Gender	Type of autonomic regulation			*p*
		sympathicotonia	normotonia	vagotonia	
SVMR, ms	♀	230.3 (209.4; 257.0)	236.8 (221.6; 264.5)	246.0 (214.3; 267.7)	$p_1 = 0.01$
	♂	235.6 (209.4; 243.1)	221.6 (205.6; 238.1)	234.0 (204.3; 243.1)	–
*p**		–	< 0.001	0.004	
SVMR SD, ms	♀	56.7 (44.9; 70.2)	60.7 (48.2; 78.0)	56.6 (42.9; 75.9)	–
	♂	51.6 (39.2; 61.3)	58.4 (46.9; 72.9)	57.2 (38.0; 77.5)	–
*p**		–	–	–	
CVMR, ms	♀	347.6 (323.0; 388.6)	354.1 (327.4; 384.4)	360.0 (340.5; 389.7)	–
	♂	357.1 (349.5; 376.8)	328.1 (310.3; 357.8)	333.3 (325.0; 366.9)	–
*p**		–	< 0.001	–	
CVMR SD, ms	♀	86.8 (76.3; 113.5)	86.6 (72.4; 101.2)	85.4 (66.8; 119.8)	–
	♂	88.1 (68.1; 128.3)	78.2 (68.7; 92.1)	79.2 (70.4; 97.7)	–
*p**		–	0.003	–	
TT (average rate), standard units	♀	6.7 (6.1; 7.1)	6.7 (6.3; 7.1)	6.9 (6.3; 7.3)	–
	♂	6.9 (6.4; 7.2)	7.2 (6.7; 7.7)	6.8 (6.5; 8.0)	–
*p**		–	< 0.001	–	
TT (number of taps), standard units	♀	200.0 (182.0; 213.0)	199.0 (188.0; 213.0)	204.5 (188.0; 217.0)	–
	♂	204.5 (190.5; 215.0)	214.0 (200.0; 229.0)	204.0 (195.0; 238.0)	–
*p**		–	< 0.001	–	

Note. ♀ – women; ♂ – men; statistically significant differences between groups: p_1 – sympathicotonics and normotonics; p_2 – normotonics and vagotonics; p_3 – sympathicotonics and vagotonics; *p** – statistically significant differences between genders; TT – tap test.

ture in which the functioning of one system depends on the work of other body systems, the correlation between organs is considered as a network dynamic interaction. The absence of correlations in this context is considered as isolation of the system (organ) in a functional sense. Based on this position, we believe that the functional diversity of the network interactions of the system determines its greater dynamic stability in the implementation of the adaptive effect. Interpreting the obtained results of the correlation analysis, it can be noted that they were the most variable in normotonics: they had 19 intersystem connections of weak and moderate strength (at $p < 0.05$) between nine indicators characterizing the elasticity of the arterial vessel wall and five morphological indicators; 10 connections between indicators of neurodynamics and morphological features of the examined and three connections neurodynamics with an aging index indicator. In all groups, a direct relationship was established between blood pressure and height and weight index, body weight and visceral fat index. The indices of elasticity of the arterial vessel wall were generally inversely related to the parameters of morphological development. Indicators of neurodynamics, indicating an increase in the performance of sensorimotor response, found a direct relationship with body weight and an inverse relationship with the value of the fat mass component.

TABLE 4

CORRELATION MATRIX OF INTERSYSTEM INTERACTIONS BETWEEN THE STUDIED INDICATORS IN STUDENTS WITH DIFFERENT TYPES OF AUTONOMIC REGULATION

Indicators	BMI, kg/m²	BW, kg	FM, %	BWP, %	VF, standard units	SVMR, ms	SVMR SD, ms	CVMR, ms	CVMR SD, ms	TT (average rate), standard units	TT (number of taps), standard units
Sympathotonics (*n* = 126)											
SBP, mmHg	0.37	0.36	0.33	–0.35	0.36	0.22	–	–	–	–	–
DBP, mmHg	0.27	0.28	0.25	–0.30	0.29	0.22	0.19	–	–	–	–
AIp75, %	–0.22	–0.29	–0.19	0.15	–0.20	–	–	–	–	–	–
Normotonics (*n* = 259)											
SBP, mmHg	0.34	0.36	–	–	0.27	–	–	–	–	–	–
DBP, mmHg	0.25	0.23	–	–	0.20	–	–	–	–	–	–
SI, m/s	–	–	–0.15	0.15	–	–	–	–	–	–	–
AIp75, %	–0.14	–0.26	–	–	–0.16	–	–	–	–	–	–
AGI, standard units	–	–	–	–		–	–	–0.12	–	0.14	0.14
RI, standard units	–	–0.20	–	–		–	–	–	–	–	–
ED, ms	0.28	0.17	0.29	–0.26	0.23	–	–	–	–	–	–
Stress index, standard units	–0.16	–	–0.13	–	–	–	–	–	–	–	–
BW, kg	–	–	–	–	–	–	–	–0.15	–0.15	0.13	0.13
FM, %	–	–	–	–	–	0.23	–	–	–	–0.16	–0.16
BWP, %	–	–	–	–	–	–0.22	–	–	–	0.15	0.15
Vagotonics (*n* = 54)											
SBP, mmHg	0.31	0.41	–	–	–	–	–	–	–	0.32	0.32
DBP, mmHg	0.41	0.49	–	–	–	–	–	–	–	–	–
SI, m/s	–	–	–0.43	0.39	–	–	–	–	–	0.35	0.35
AIp75, %	–0.31	–0.55	0.49	–0.47	–	–	–	–	–	–	–
AGI, standard units	–	–	0.41	–0.39	–	–	–	–	–	–0.34	–0.34
RI, standard units	–	–0.28	0.34	–0.32	–	–	–	–	–	–	–
ED, ms	–	–	0.34	–0.30	–	–	–	–	–	–	–
BW, kg	–	–	–	–	–	–	–	–0.31	–	–	–

Sympathicotonics revealed the least intersystem connections, they had the unidirectionality of correlations of weak and moderate strength between blood pressure, augmentation index, morphological development indicators and SVMR indicators.

In the group of vagotonics, moderate strength connections with morphological development and elasticity of arterial vessels were noted. At the same time, it is possible to note a more pronounced connection between the elasticity of arterial vessels with the water and fat mass components of the body. Six of the seven identified connections of neurodynamic characteristics are related to vascular tone indicators.

DISCUSSION OF RESULTS

According to the study [14, 15], the values of elasticity of the vascular wall of the arteries act as prognostic indicators in the development of arterial hypertension, which is especially relevant in the conditions of the northern region [2, 3]. An increase in arterial stiffness leads to an increase in central blood pressure and an increase in afterload on the heart. It contributes to the restriction of coronary blood flow, which leads to a decrease in the contractility of the myocardium. Analyzing the indicators characterizing the functional state of the arterial vascular wall in students with different types of autonomic regulation, we assume the existence of several mechanisms to maintain an optimal blood pressure level. An increase in the stiffness of the vascular wall of large and small arteries, expressed in an increase in the augmentation index and the resistance index in groups of young women, is noted with an increase in parasympathetic activity; in young men, an increase in the stiffness of large arteries increases with an increase in sympathoadrenal activity, while there is a compensatory increase in the stiffness of small muscular arteries with an increase in parasympathetic activity.

From our point of view, in the group of young women with a high level of sympathetic activation of the central mechanisms of regulation of the cardiovascular system, the hyperkinetic type of blood circulation is insufficiently compensated by the elasticity of large arteries, which causes a decrease in the tone of small muscular arteries, despite increased sympathetic activity. In the group of young women with high parasympathetic activity, a decrease in the elastic properties of large arteries leads to an increase in afterload on the myocardium, which reduces peripheral blood flow, that requires an increase in peripheral arterial tone. The combined effect of these mechanisms further increases the afterload on the heart and excessive stimulation of the mechanisms of regulation of vascular tone can contribute to depletion of nitrogen monoamine production. This allows us to make an assumption about the more pronounced risks of cardiovascular disorders in young women with high parasympathetic activity.

In the group of young men with a high level of sympathetic activation of the central mechanisms of regulation of the cardiovascular system, a decrease in the elasticity of large arteries and an increase in afterload on the heart are partially compensated by a decrease in the tone of small peripheral arteries, despite the sympathetic activation of vascular tone regulation. From our point of view, this imbalance of regulation indicates an increased risk of cardiovascular disorders in this group of examined students. In the group of young men with high parasympathetic activity, the high elasticity of the vascular wall of arterial vessels does not provide adequate peripheral blood flow, which requires an increase in the tone of small arteries to maintain it. The resulting constant stimulation of nitrogen monoamine production can lead to depletion of the mechanisms of its formation.

The absence of statistically significant differences in the rate of pulse wave propagation (SI) characterizes the preservation of the elastic properties of the aorta, characteristic of young people. With increasing parasympathetic activity and decreasing average HR, ejection duration compensatory increases.

Thus, an analysis of the features of the regulatory mechanisms of the cardiovascular system revealed that in groups of young men and women with a high level of sympathetic activation of the central mechanisms of regulation of the cardiovascular system, the risks of disorders in this system are associated with dysregulation of vascular tone (decreased tone of small arteries against the background of increased activity of the sympathetic nervous system). The predominance of parasympathetic influence in the regulation of heart rhythm against the background of high elasticity of large arterial vessels and increased tone of small arterial vessels allows us to conclude that there are higher needs for capillary blood flow of organs and tissues. The noted imbalance in the regulation of blood circulation suggests that in groups of young men and women with high parasympathetic activity, the risks of impaired blood flow are associated with a possible depletion of the mechanisms of production of nitrogen monoamine as one of the leading factors in the development of arterial hypertension.

A decrease in heart rate variability and, consequently, an increase in stress index are associated with a high risk of cardiovascular pathology. The absence of people with pronounced manifestations of cardiac pathology in the examination cohort, moderately high stress index indicators in the groups of sympathotonics, probably indicate the presence of a genetically determined stress-induced response of the latter's body.

The results of the assessment of the anthropometric indicators of students obtained by us indicate the optimal physical development of the majority of the examined students. According to a study by the team of authors presented in [16], the body mass index currently is an objective tool for obesity screening. The average BMI values fit into the medial values of the reference norm range, which states the dominance of mesosomatotypes in the cohort of the study. Modern scientific studies [17] characterizing the average anthropometric indicators of students state that the height of young men

is 170–177 cm, young women – 160–165 cm; the average body weight of young men is 68–72 kg, young women – 55–57 kg. However, the results of the assessment of the physical development of students in the Ural region, presented in our previous work [18], allowed us to establish statistically higher BMI and body weight due to a higher content of body fat, visceral obesity and a statistically significantly lower body water percentage in students in Surgut compared with students in more southern territories. I.V. Averyanova [19] showed that among men born in the North, there is also a prevalence of persons with a hypersthenic type of constitution, overweight and signs of obesity. The results obtained are consistent with the global and all-Russian trend of a higher prevalence of overweight in a cohort with high social and economic status and income [20].

The revealed intersex features of the body composition of the examined students reflect the general population trend [21] of a higher fat content in the body of young women, which is consistent with the studies of a number of other authors. Studying age-related changes in BMI and fat mass component of both genders, C. Palomino-Devia et al. [22] state that with age, an increase in BMI in young women is combined with an increase in fat mass ($p < 0.05$); in young men – with a decrease in fat mass ($p < 0.05$) and an increase in the muscular component of the body.

The most optimal body composition was noted in the groups of vagotonics and normotonics. The average content of fat and water components of the body of students belonging to these groups corresponded to the normative values. According to our data, the predominance of sympathoadrenal activity in ensuring the regulation of the rhythm of cardiac activity of the body is characterized by an excessive content of fat mass and visceral obesity, water insufficiency in students, which is confirmed by other modern studies [23]. Physiologists note the need to take into account the characteristics of body composition of the examined in the prediction and prevention of various nosologies. In particular, overweight and obesity are the leading risk factors for the development of cardiovascular [24] and endocrine pathologies [25]. Excess body fat causes the formation of extensive inflammatory processes in the body, leading to cancer and the progression of many types of tumors [26], increases cancer mortality by up to 20 % [27]. It was found that with an increase in the fat component, both young men and women experience a decrease in the water level in the body [28]. Water plays a crucial role in ensuring the normal functioning and maintenance of homeostasis, and is also an indirect indicator of preload of the heart. The deficient content of the liquid component of blood plasma causes an increase in the load on the contractile function of the myocardium due to a violation of the rheological properties of blood.

Our results indicate that with the predominance of parasympathetic regulation of heart rate, inhibitory processes in the central nervous system increase, there is a decrease in activating effects, expressed in average indicators of a simple sensorimotor reaction and in conditions of sensory differentiation of the visual stimulus. This pattern is most clearly seen in groups of female students. In the group of sympathicotonic male students, the variability of the average values of SVMR and CVMR reflects the least favorable level of performance in conditions of both simple and complex sensory load, which reflects the reduced activation of the central nervous system and attention switching of the latter compared with young men of other types of autonomic regulation. The indicators of variability of the average indicators of SVMR and CVMR (SD) reflect the well-established relatively stable manifestations of sensorimotor reactions of students of different sexes and with different types of autonomic regulation.

Relatively high neuromuscular performance in terms of the tap test in young women is characteristic of vagotonics, in young men – normotonics. Large values of the upper quartile of the tap test indicators in normotonic young women and vagotonic young men allow us to note their relatively better performance (endurance) compared to sympathicotonics of both genders. Intersex differences are clearly manifested in the results of neurodynamic testing in normotonics. Young men are characterized by a more effective sensorimotor response and a more advanced mechanism of differentiation inhibition of conditioned reflex activity, which is consistent with the literature data [29].

The results of a comprehensive study of intersystem connections of blood flow indicators, morphotype and neurodynamics obtained using correlation analysis revealed statistically significant weak and moderate strength connections between the studied parameters. Direct and inverse connections, along with the elements of the system, make up its structure; their analysis expands the understanding of the mechanisms of subordination, redistribution, reactivity between the individual components of the links of homeostasis. As R.M. Bayevsky notes [30] that almost all functional systems of the body participate in adaptation, one of the leading roles in it belongs to the cardiovascular system, which ensures the vital activity of the body at an optimal homeostatic level and is the most sensitive indicator of the productivity of adaptive reactions. In this regard, there is a special group of sympathicotonic students, in which the number and severity of correlations are less variable, which indicates greater stiffness (compared with groups of vagotonics and normotonics) of the regulation mechanisms in achieving a positive adaptation result.

CONCLUSION

In the majority of the examined students of the pedagogical university of the Northern region, the indicators of the cardiovascular system, body composition and neurodynamic processes correspond to the reference values.

The intersex differences in the mechanisms of maintaining optimal blood pressure, body composition and neurodynamic performance in students of different

types of autonomic regulation were revealed. For individuals with a high level of sympathetic activation, the risks of disorders are associated with dysregulation of vascular tone; for individuals with a predominance of parasympathetic activity – with a possible depletion of the mechanisms of nitrogen monoamine production. In persons of the sympathicotonic type of autonomic regulation, body composition is due to an excessive content of fat mass and visceral obesity, water insufficiency. In the implementation of neurodynamic reactions, it is noted that with the predominance of parasympathetic regulation of heart rate, inhibitory processes in the central nervous system increase. In young men, reduced sensorimotor reactions are also consistent with sympathetic activation in the regulation of heart rate.

The correlation analysis between the parameters of the morphofunctional state in students with different types of heart rate regulation made it possible to establish some features in the interaction of physiological systems: vascular, morphological and central nervous systems.

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Conflict of interest

The authors of this article declare the absence of a conflict of interest.

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