



# Optimization of the Adaptation Process during Physical Education Classes When Implementing an Individual Approach Based on the Autonomic Regulation Types of the Functions of the Cardiovascular System

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## Abstract

**BACKGROUND:** The relevance of the study is determined by the negative dynamics of the health of children groups in the Russian Federation, which necessitates the search for effective methods of health-improving and corrective effects in physical education classes in schools. The physiological substantiation of the individualization of the selection of physical activities is based on the differences in the functional state of schoolchildren with different autonomic regulation types of the cardiovascular system.

**METHODS:** The method of "Rapid assessment of schoolchildren's physical health" based on an automated computer program, which allows determining the state of the functional systems (cardiovascular, respiratory, and musculoskeletal systems) of the children's organisms by 20 indicators. A method for diagnosing heart rate variability indicators, implemented using the Varikard 2.51 software and hardware complex, allows obtaining and analyzing more than 40 indicators of segmental and suprasedgmental levels of regulation of the cardiovascular system and parameters of its functional activity. The complex application of these methods provides a comprehensive physiological picture of the adaptation, health, and functional state of school students when performing various physical activities in the educational process.

**RESULTS:** At the beginning of the survey, the indicators of functional systems and heart rate variability in the selected groups of children: The experimental group and the control group were determined by the features of four autonomic regulation types: I, II, III, and IV. Of these, I, II corresponded to the predominance of sympathetic tonic destabilizing effects on the cardiovascular system, while in IV, parasympathetic effects on the cardiovascular system prevailed, manifested in the asthenization of the functional state of children. Type III refers to the physiological norm and manifested itself in the form of a balance of regulatory influences of the parts of the autonomic nervous system. At the physical education classes of experimental group schoolchildren, the training program included specially selected sets of exercises for children with autonomic regulation types I, II, III, and IV.

**CONCLUSION:** During the control examination, the indicators of adaptation and health of all types of schoolchildren improved, while no positive dynamics of physical strength, adaptation, and health indicators were observed in the control group. This indicates the effectiveness of individually typologically oriented physical education classes as having a health-improving effect on school students.

## Introduction

The health of the younger generation is one of the most important problems of the 21<sup>st</sup> century. The increased attention of scientists and teachers to the health of children is explained by the deterioration of the demographic situation in the Russian Federation (RF) [1], [2].

In the process of ontogenesis in the system of regulation of the heart rhythm, individual features of the formation of the tone of the autonomic nervous system (ANS), its instability against the background of age-related features of the growing organism, and adaptation to various external influences are observed.

When determining the causes of heterogeneity and instability of neurohumoral regulation of heart rate (HR) in children and adolescents, researchers point to the multifactor nature of this phenomenon: Constitutional and genetic imbalance of the mechanisms of regulation of physiological functions, and critical periods of functional maturation of the ANS in ontogenesis causing tension of adaptive mechanisms [3], [4], [5], [6], [7]. In Shlyk [6], four types of regulation were identified, differing in ratios of interactions between the sympathetic and parasympathetic parts of the ANS structures of the cerebral cortex and subcortical areas. According to Shlyk, the autonomic regulation type (ART) is genetically determined and persists in 82% of children, and the predominance of sympathetic HR regulation

in childhood should not be considered a physiological norm [8], [9].

According to Shlyk *et al.* [10], Kolomiets and Bykov [11], individual typological autonomic regulation in children aged 10–15 years is associated with a specific configuration of hypothalamic-pituitary regulatory hormones and hormones of the endocrine system of the body, which reflect the level of adaptive and compensatory resources of the child's organism [12], [13], [14], [15], [16], [17].

In the course of educational activities involving mental stress in general education classes and physical exertion in physical education (PE) classes of various nature, there is a complex influence of environmental factors on the nervous and endocrine mechanisms of regulation of physiological functions. Neurohumoral shifts that occur in children in the process of adaptation to physical activity differ in many ways from those in adults, since they provide complex processes of growth and development of the child's organism [18], [19], [20].

## Methods

### ***We used an automated computer program (ACP) "Express Assessment of Schoolchildren's Physical Health (PH)"***

For rapid assessment of physical development (PD), health, the state of the functional systems of the organism, and their deviations from the norm, the program uses well-known motor indices: Quetelet (QI), Robinson (RI), Skibinsky (SI), Shapovalova (ShI), Rufier (RufI). To obtain the results of calculating the ACP indices of PD and health in schoolchildren, we measured functional indicators and performed motoric tests [21].

### ***Varicard 2.51 software and hardware complex***

The analysis of HR variability (HRV) indicators was carried out based on electrocardiogram (ECG) registration by the Varicard 2.51 hardware and software complex, which allows calculating up to 40 different parameters of the functional state of the body recommended by both Russian and European/American standards in the field of cardiological research [22], [23].

### ***Organization of the study***

#### ***Distribution in groups***

At the beginning of the study, the motor abilities of students were determined. We collected general anamnesis and information about social status,

lifestyle, physical education, sports, work, rest, state of health, indicators of the functional state, ANS, CNS, and spatio-temporal properties. In addition, we considered injuries due to physical education and sports and the possibility of resuming classes.

60 schoolchildren of the 6<sup>th</sup> grade aged 12 years were examined, of which two groups consisting of 30 students each were formed, namely, the experimental group (EG) and the control group (CG), similar in terms of functional state and level of physical development. Measurements were carried out in the morning hours, highlighting the control stage of the initial examination, which forms the stage during which the children of the EG were engaged in special PE classes for 6 months (October 2019–April 2020, duration of classes 45 min) according to the developed individual typological program. The students of the CG studied according to the school curriculum. The examination was carried out both at the beginning of the study for the EG and CG and at the end of the study, on receipt of the final results of the study.

After the end of the training period, a final (control) examination was conducted in conditions similar to the initial ones and using methods similar to the initial examination.

### ***Mathematical and statistical analysis***

The results were processed using the SPSS statistical software, version 17.0 for Windows. Methods of comparing Student's T-test averages for paired samples were used. Euclidean distance method, determines the distance between two nearest variables.

## Results

### ***Forming individual typological programs of physical activity in PE classes***

Based on physiological studies of HRV types and determination of motor indices, formative individual typological programs for PE classes were developed for the EG, where physical loads and types of exercises were selected taking into account the ART for the cardiovascular system (CVS) functions. The programs had a developmental and wellness orientation. The content of the programs is presented in Table 1.

### ***The change in the schoolchildren's health index (HI) during physical adaptation, depending on the individual typological status***

Figures 1 and 2 show a pie chart with HRV indicators in school students with different ARTs in the EG at the initial and final stages of the study. EG

children were engaged at the formative stage of the study according to individual and group programs, compiled taking into account the ART, which was determined by the functional state of the cardiovascular system. The division of children into groups by ARTs fully corresponds to the classification of N.I. Shlyk and includes 4 types of regulation that have distinctive features of controlling the functions of the cardiac system of schoolchildren. Figures 1 and 2 shows a pie chart of the measured HRV indicators in schoolchildren with ARTs I-IV of the cardiac system in the EG at the initial (Figure 1) and the final stages (Figure 2) of the examination of children.

**Table 1: Physiological substantiation of the choice of typologically oriented exercises in physical education classes for schoolchildren with autonomic regulation types I, II, and IV**

Schoolchildren in the EG with ARTs I, II, and IV were offered typologically oriented corrective physical exercises, in contrast to the CG schoolchildren who had a school curriculum based on the FGOS of PE used in the RF  
ART I of CVS functions

For schoolchildren with ART I who had a moderately increased level of activity of the sympathetic part of the ANS exercises aimed at increasing physical fitness and fitness with controlled physical activity were selected. At the same time, there was a decrease in sympathetic activity, the balance of the CNS increased, the effect on the functional systems of the body was optimized by systematically training physical influences

ART II of CVS functions

For children of the period of second childhood and adolescents with ART II, where sympathicotonia was significantly pronounced, exercises using the stretching method for stretching ligaments and muscles, increasing body flexibility were offered. This method helps to reduce muscle tone, relaxation, and trophism improvement by increasing blood circulation in the muscles. The effect of stretching on the CNS is manifested in a decrease in sympathetic activity and regulation of the processes of excitation and inhibition in the cerebral cortex to achieve a balanced state of the CNS

ART III of CVS functions

Children of second childhood period and adolescents with a moderate prevalence of autonomous regulation with ART III adapt to physical stress due to the tension of the central structures of regulation. In this case, the value AMo50 (a conditional indicator of the activity of the sympathetic link of the regulation) and the SI significantly increase, while the HRV cumulative spectral power values decrease (TP is the total power of the HRV spectrum, HF is the value of the total power of the spectrum of the high frequency component of HRV, LF is the value of the total power of the spectrum of the low frequency component of HRV, and VLF is the value of the total power of the spectrum of the very low frequency component of HRV waves). These data indicate the most optimal interaction between the sympathetic and parasympathetic parts of the ANS and central structures in the process of regulation of HR. This state of the organism can be taken as the physiological norm of the functional state of regulatory systems reflecting the high adaptive capabilities of the organism. These children had a normal school curriculum

ART IV of CVS functions

For schoolchildren with ART IV where parasympathetic influences on the CVS significantly predominated, outdoor games, relay races, aerobic exercises with moderate intensity were proposed, affecting the normalization of blood circulation and the development of adaptive reactions of the children's organisms, and reducing the predominance of activity of the parasympathetic part of the ANS

When choosing the volume and intensity of physical activity in PE classes used as a formative effect on the physical development of school students, the duration of the interval of motor activity and rest between repeated loads is essential. Taking into account the type of energy supply made it possible to control the performance of motor tasks by students with different ARTs with the required duration, rest interval, and the number of repetitions in class

EG: Experimental group, ARTs: Autonomic regulation types, PE: Physical education, CG: Control group, FGOS: Federal State Educational Standards, RF: Russian Federation, CVS: Cardiovascular system, ANS: Autonomic nervous system, CNS: Central nervous system, SI: Stress index, HRV: Heart rate variability.

The use of a physiologically justified load in PE classes, taking into account the ARTs, provides an improvement in the regulation of physiological indicators and an approximation of HRV indicators to the optimal values of the *physiological norm* in the EG schoolchildren (Figure 2).

Figures 3 and 4 show a pie chart of HRV indicators by ARTs in the CG at the initial and final stages of the study.

In the CG, at the final stage of the study (Figure 4), there was no stabilization of HRV indicators

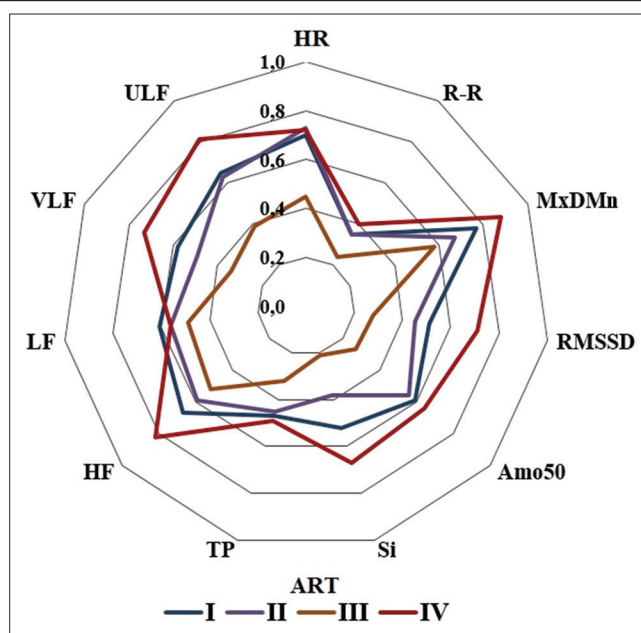


Figure 1: Distribution of HRV indicators by ARTs in EG at the initial stage of the study

compared to the beginning of the experiment (Figure 3). This indicates the need for the use of specially selected PE and wellness programs and correctional physical exercises, which were used in the EG, at PE classes conducted with schoolchildren of the CG following the educational standards in force in the RF. Figures 5 and 6 and Tables 2 and 3 show the distribution of HI indicators in students with I, II, III, and IV HRV types at the initial and final stages of the study in the EG.

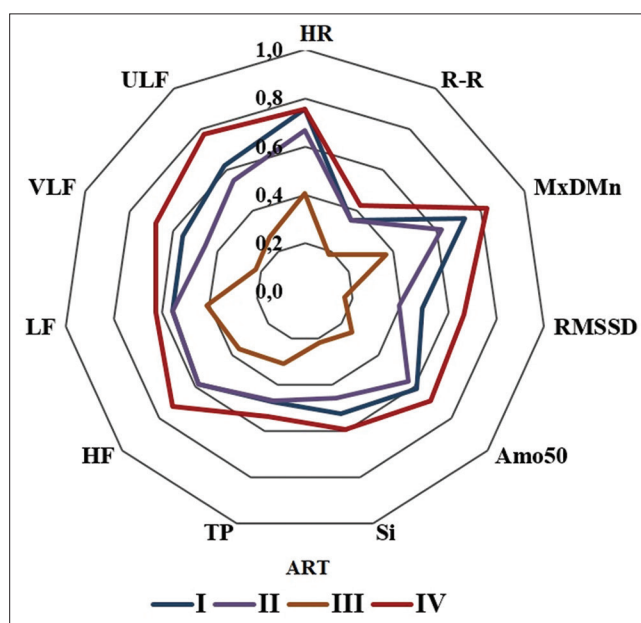


Figure 2: Distribution of HRV indicators by ARTs in the EG at the final stage of the study

Analyzing Figures 5 and 6, it can be found that in children with ART III, the indicators of integral indices of physical development and health have optimal values (are in the optimal sphere) of the diagram, in contrast to schoolchildren with ARTs I, II, and IV. The RI, SI, ShI,



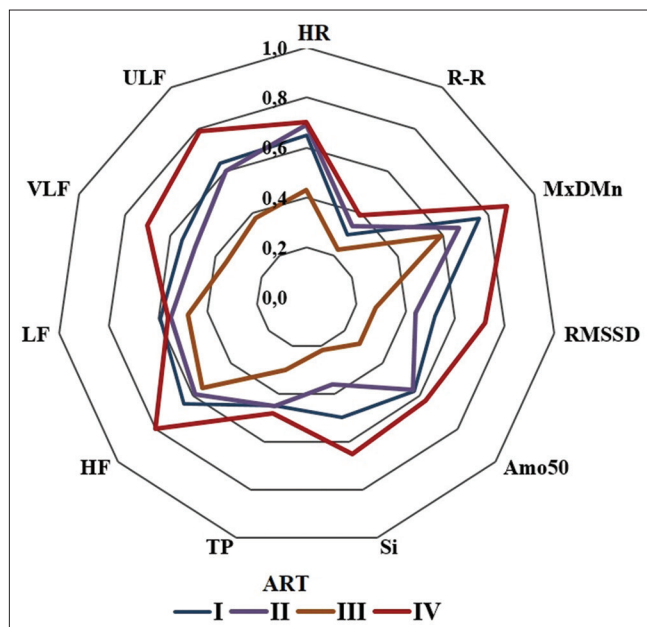


Figure 3: Distribution of HRV indicators by ARTs in the CG at the initial stage of the study

Rufl, and QI have values corresponding to the optimal ones. The results can be considered optimal because

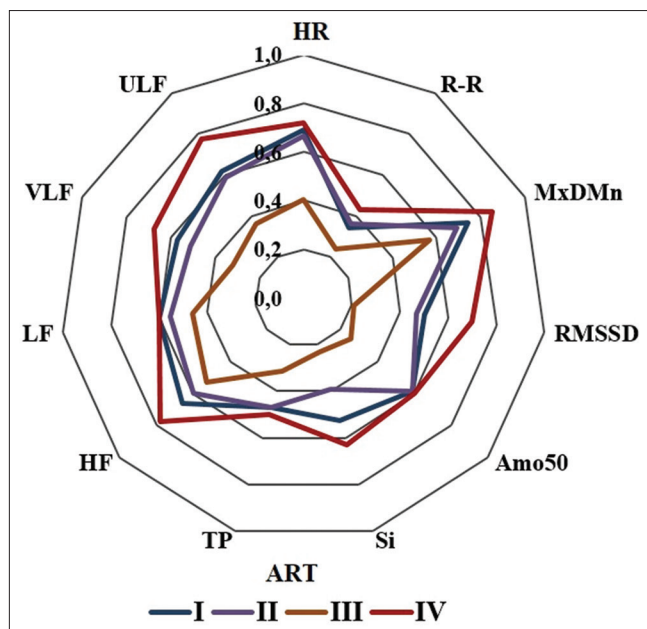


Figure 4: Distribution of HRV indicators by ARTs in the CG at the final stage of the study

students with type III autonomic regulation have values of integral indices related to the norm (Tables 2-5).

Table 2: Calculation of indicators of the derivative stimulus configuration by types of autonomic regulation and health indices at the beginning of the study in the experimental group

At the beginning of the study	I	II	III	IV
Rufier index	0.65	0.72	0.60	0.73
Robinson index	0.69	0.68	0.44	0.61
Quetelet index	0.65	0.39	0.42	0.64
Skibinsky index	0.71	0.71	0.53	0.70
Shapovalova index	0.71	0.62	0.57	0.62

Figures 5-8 show the distribution of health indices for different types of vegetative regulation of the expected norm indicators in conventional units from 4 to 6 conventional units.

Table 3: Calculation of indicators of the derivative stimulus configuration by types of autonomic regulation and health indices at the end of the study in the experimental group

At the beginning of the study	I	II	III	IV
Rufier index	0.59	0.62	0.56	0.65
Robinson index	0.64	0.62	0.44	0.66
Quetelet index	0.63	0.45	0.43	0.60
Skibinsky index	0.57	0.60	0.57	0.62
Shapovalova index	0.67	0.63	0.51	0.67

Schoolchildren with ART III have the smallest variation in HRV indicators. Minimization of HRV may indicate functional stability and sufficient adaptive reserves, stability of integrative mechanisms of the cardiorespiratory system to external influences in the

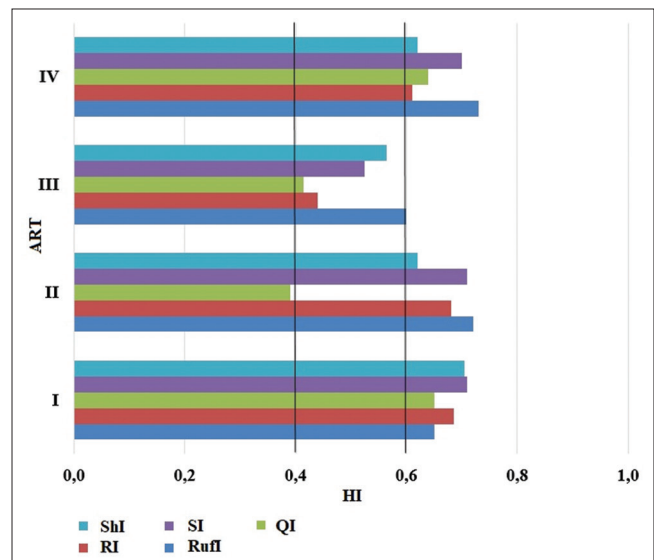


Figure 5: Distribution of the HI indicators in children with I, II, III, and IV HRV types at the initial stage of the study in the EG. ShI: Shapovalova index; SI: Skibinsky index; QI: Quetelet index; RI: Robinson index; Rufl: Rufier index; HI: Health index

form of motor loads in PE classes (Figure 6). At the initial stage of the study, the indicators from in the EG had significant deviations from the norm values and the greatest range of values was observed in the considered ARTs I, II, and IV. At the final stage of the study, the range of HI in the EG decreased that indicates the balance of adaptation systems and their stability due to the use of a typologically oriented load.

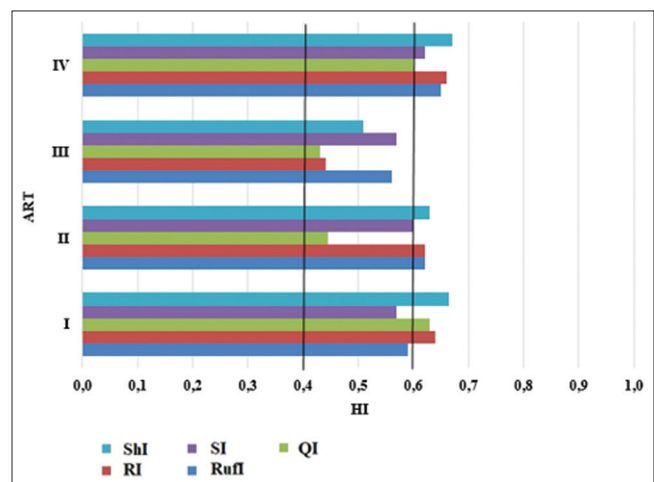


Figure 6: Distribution of the HI indicators in children with I, II, III, and IV HRV types at the final stage of the study in the EG

Figures 7 and 8 and Tables 4 and 5 show the distribution of HI indicators in CG schoolchildren with I, II, III, and IV HRV types at the initial and final stages of the study.

**Table 4: Calculation of indicators of the derivative stimulus configuration by types of autonomic regulation and health indices at the beginning of the study in the control group**

At the beginning of the study	I	II	III	IV
Ruffier index	0.63	0.71	0.59	0.71
Robinson index	0.71	0.72	0.44	0.62
Quetelet index	0.64	0.38	0.43	0.64
Skibinsky index	0.69	0.73	0.52	0.71
Shapovalova index	0.71	0.62	0.60	0.65

It is important to note that at the final stage of the study, in the CG, the RI, SI, ShI, Rufl, and QI have deviations from the values of the physiological norm and the greatest value range in the ARTs I, II, and IV, indicating the imbalance in the systems of adaptation and instability in the regulation of the CNS compared to the EG (Figure 8).

**Table 5: Calculation of indicators of the derivative stimulus configuration by types of autonomic regulation and health indices at the end of the study in the control group**

At the end of the study	I	II	III	IV
Ruffier index	0.65	0.70	0.60	0.72
Robinson index	0.70	0.69	0.45	0.63
Quetelet index	0.68	0.38	0.43	0.66
Skibinsky index	0.70	0.70	0.50	0.70
Shapovalova index	0.72	0.64	0.61	0.68

Consideration of changes in the HI of children depending on the individual typological status shows that the variability and values of HI in the group of children with type III HRV under the influence of physiologically justified motor load have stabilized, and their range has decreased. The ShI (speed and strength endurance of the muscles of the back and abdomen) and RI (reaction of the cardiovascular system to physical activity) showed pronounced positive dynamics. The range of indices deviating from the norm values in groups of types I, II, and IV decreased moderately in the EG. These data indicate a decrease in tolerance to motor load, especially pronounced in children with type IV regulation of the cardiac system.

Therefore, ART is the most important physiological indicator that determines the functioning of the human organism. Formation of the regulation type as a phenotypic trait is carried out under the influence of environmental factors, including motor activity. Individual typological characteristics also depend on the state of the nervous, cardiovascular, respiratory, and other functional systems of the body of children, which change in ontogenesis under the influence of physical activity.

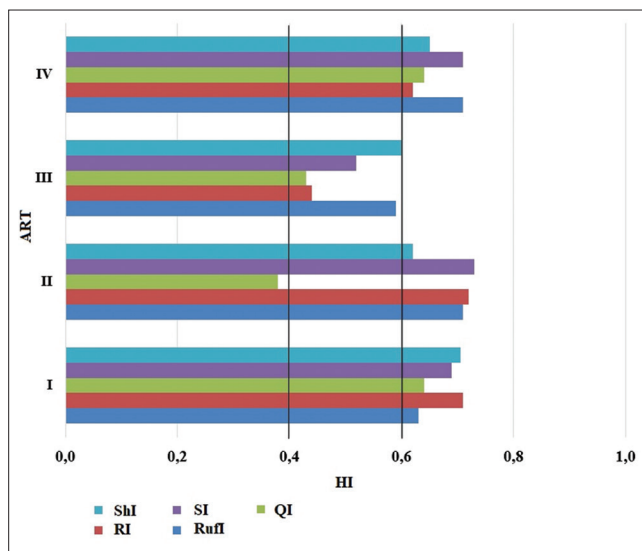


Figure 7: Distribution of the HI indicators in schoolchildren with I, II, III, and IV HRV types at the initial stage of the study in the CG

Table 6 shows HRV indicators in schoolchildren of the age of second childhood at the end of the study in the EG and CG ( $M \pm m$ ).

The optimal state of regulatory systems is noted in the EG (Figure 6); after additional classes, the functions of the CNS are balanced. It can be concluded that long-term adaptation, expressed in ANS balance and vestibular stability during classes, is due to the use of exercises taking into account the ARTs that optimize the functional state of the CVS, which acts as an indicator of the level of adaptive capabilities of the schoolchildren's bodies.

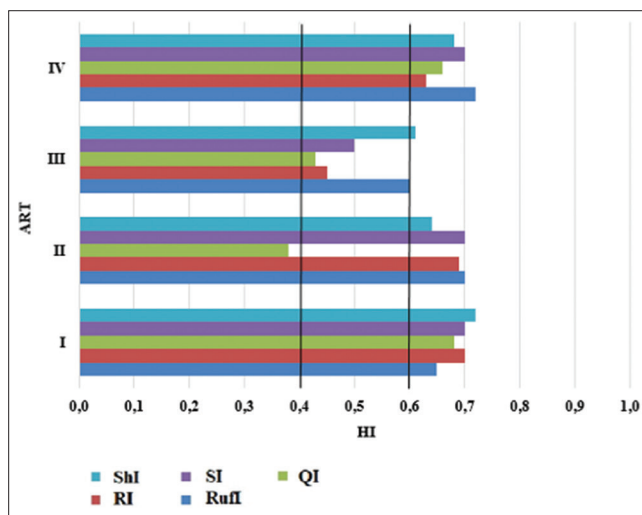


Figure 8: Distribution of the HI indicators in schoolchildren with types I, II, III, and IV at the final stage of the study in the CG

In CG, there is an imbalance of autonomic regulation, a pronounced increase in the activity of the vasomotor center regulating vascular tone, and a weakening of the activity of the sympathetic cardiovascular center, which manifests itself in reduced functional indicators of students compared to the EG.

**Table 6: Heart rate variability indicators in schoolchildren of the second childhood period (12 years) at the end of the study in the experimental group and control group (M ± m)**

HRV Types	HR, bpm	R-R (ms)	MxDMn (ms)	RMSSD (ms)	Amo 50%/50 (ms)	SI (CU)
Type I						
EG	90.4* ± 1.2	664.8* ± 21.6	249.9* ± 12.4	37.1 ± 1.8	47.2* ± 1.2	139.3* ± 12.4
CG	92.1 ± 0.9	642.35 ± 23.2	221.1 ± 11.4	34.8 ± 0.9	52.8 ± 1.8	153.5 ± 10.8
Type II						
EG	91.8* ± 1.04	629.4* ± 11.5	225.6 ± 7.9	32.8* ± 1.1	63.1** ± 1.2	160.2* ± 11.3
CG	93.42 ± 0.75	611.1 ± 22.1	212.5 ± 9.1	27 ± 1.3	67.3 ± 0.7	233 ± 53.4
Type III						
EG	83.4* ± 1.4	803.9* ± 24.2	338.9* ± 13.3	64.3* ± 1.9	30.9** ± 0.9	64.6* ± 2.2
CG	86.9 ± 0.6	766.6 ± 6.8	313.8 ± 14.1	61.9 ± 1.3	33.4 ± 0.75	69.3 ± 2.5
Type IV						
EG	68.1* ± 1.5	868.2* ± 9.5	527.2* ± 14.04	120.4* ± 6.9	22.4 ± 0.7	14.9 ± 1.9
CG	75.4 ± 1.5	838.6 ± 11.08	481.9 ± 9.8	123.7 ± 8.66	18.2 ± 0.8	13.1 ± 1.16

\*p < 0.05, \*\*p < 0.01. EG: Experimental group, CG: Control group, HR: Heart rate, SI: Stress index.

In the future, the results obtained will allow us to recommend using psychophysiological diagnostics of sensorimotor response and HRV of schoolchildren more widely to choose the most effective way to increase readiness for educational activities and achieve tolerance of educational physical loads, as well as their typological selection depending on the ARTs of CVS functions.

According to the research of R.M. Bayevsky [2], HRV reflects the work of the mechanisms of regulation of the whole organism and not only the cardiovascular system. Therefore, using the HRV method for registered deviations in the functions of the cardiovascular system one can determine the adaptation and level of health. One can assess health deviations from the state of the norm, transition to a pre-nosological state, or a state of a significant decrease in the activity of regulatory systems due to their depletion in students.

In our study, we received confirmation of these previously established results R.M. Bayevsky. The study shows that when using typologically oriented exercises, the establishment of a balance of the sympathetic and parasympathetic parts of the autonomic nervous system, normalization of the activity of the subcortical cardiovascular center, pronounced weakening of the activity of the sympathetic cardiovascular center is observed.

## Conclusion

In schoolchildren with ART III, HRV indicators and integral indices of physical development and health, namely, RI, SI, ShI, Ruffl, and QI have optimal values, unlike schoolchildren with ARTs I, II, and IV. When using typologically determined physical activity in ARTs I, II, and IV, students had an improvement in HI and minimization of HRV, which indicated functional stability and sufficient adaptive reserves, as well as the stability of the integrative mechanisms of the cardiorespiratory system to the loads in the PE classes. The complex application of HI and HRV makes it possible to develop *physiologically substantiated motor load programs* for use in PE classes at educational institutions.

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