Original Article

Individual and typological factors influencing the regulation of physiological adaptation to physical activity of schoolchildren with different age and gender

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ABSTRACT

The article presents results of a comparative survey of cardiovascular system parameters and of integral indexes of physical health diagnostics in differentiated groups of children by age and sex. The children being examined are of 11, 12, 13, 14, 15, and 16 years old. We studied the dynamics of adaptation processes, which are determined by the sex-age features of the ontogeny of the child's organism and by environmental factors, affecting the development of physical activity in the course of physical education in educational institutions. In addition, we have established sex-age patterns of children's adaptation at the stages of second childhood, adolescent, and early adolescence. The results obtained contribute to a new field of physiology, age adaptology, which allows to predict and prevent dysontogenetic abnormalities in the development of the child's organism. **Keywords:** Age physiology; Adaptogenesis; Sexual dimorphism; Heart rate variability parameters; Health assessment indices; Physical education; Age adaptology.

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INTRODUCTION

Because of the growing instability of life-supporting factors, such as environmental, socio-psychological, and information ones, disadaptive tendencies in the formation of children's health have become sustainable in the Russian Federation. This stimulates the study of physiological mechanisms of adaptive reactions the children's organism has at all stages of ontogeny, especially in the child and adolescent period, which is the most sensitive to the influence of endogenous and exogenous factors on the organism's development. The maximum influence of the family and social-educational environment during the child and adolescent stages of ontogeny leads to increasing risks of disadaptation and health disorders (Apanasenko, 2000; Bezrukikh, Sonkin & Farber, 2003).

With a significant amount of research devoted to the issues of human adaptation in the Russian science, adaptive mechanisms in the context of age still remain understudied (Bets, 1999; Bogdan, 2000; Volozhin, & Subbotin, 1998; Nikolayev, 2001). This is especially true for the study of regulatory processes of both central neuroendocrinal links, as well as vegetative regulatory contours (Baevsky, 2001; Polina & Krivitsky, 2016). This is due to the instability and variability of the processes of formation of the functional systems in children's organism, physiological fluctuations in the activity of the central nervous system's cortical and diencephalic regions, determing certain features of children and adolescents' development, as well as their adaptation to physical and mental stress that certainly increase in the learning process (Salivon & Polina, 2002; Sitdikov & Sheykhelislamova, 2008).

Due to new functional methods for diagnosing heart rate variability (HRV) in children, new data can be obtained, making it possible to differentiate neurohumoral effects of central and vegetative regulatory links on children's cardiovascular system when adapting to dynamic muscular exercises (Baevsky, 2001; Sitdikov & Sheykhelislamova, 2008; Skrigan, 2016).

One should note that the data in the field of physiology of physical culture and sports on the features of adaptation to adults' physical exercises cannot be applied to the child, adolescent, and early youth stages of ontogenesis, because their neurophysiological mechanisms of adaptation regulation differ from those that adults have in many ways (Nikolayev, 2001; Polina & Krivitsky, 2016; Salivon & Polina, 2002). Therefore, the research on children's physical activity at different stages of ontogeny, intensity of physical exercises, and adaptation to them is very relevant.

Deficiency of physical activity causes dysontogenetic developmental disorders. Their prevention and rehabilitation are impossible without a proper understanding of the mechanisms of the children's organism adaptation to physical exercises. On the other hand, physical loads, which are inadequate in terms of their size, duration, structure, as well as age-related adaptive and psychophysical capabilities of the children's organism can exert a stratogenous influence, leading to physical and emotional overloads, negatively influencing the normogenesis, and causing overstrain and disruption of the regulatory systems' functions (Baevsky, 2001; Bets, 1999; Skrigan, 2016; Sonkin & Kuznetsova, 2009; Spivak & Nezhkina, 2014).

Analysis and generalization of the scholarly literature on this topic show the complexity and integrative nature of the children's adaptogenesis in the course of their individual development. Children experience numerous and complex environmental influences in addition to the influence of previous stages of ontogeny on all subsequent stages. Therefore, we consider the development of the age-related adaptology a reasonable and timely research agenda aimed at conducting interdisciplinary studies in the field of adaptology and age psychology for a better understanding of the complex and contradictory process of human development and adaptation in the child, adolescent, and youth stages of ontogenesis (Nikolayev, 2001). In our opinion, the study of adaptation processes and risk factors of disadaptation of children at all stages of their ontogenesis should be the main goal of the new field of physiology.

Natural, climatic, and socio-psychological factors that affect children's activities, such as lifestyle deformations, educational and physical overloads, can cause a significant predominance in the functioning of one part of the autonomic nervous system. This condition manifests itself in the functional dominance of the sympathetic or parasympathetic parts of the autonomic nervous system, which can be observed in a significant majority of children (Volozhin, & Subbotin, 1998; Polyakov, 2002). These children are included in a group of conditionally healthy, but at the same time having significant stress (strain) and risks of exhaustion of adaptation resources, which can eventually contribute to the disruption of the physiological functions in the children's organism (Nikolayev, 2001; Polina & Krivitsky, 2016; Salivon & Polina, 2002).

The cardiovascular system makes a decisive contribution to the adaptation processes. In the process of children's ontogeny, the system of regulation of the cardiovascular system functions and heart rate, its leading indicator, exhibit individual features of the formation of the autonomic nervous system tone in childhood. At the same time, one may observe instability in the autonomic nervous system tone against the background of the age features of the growing organism and its adaptation in different age periods to external influences (Shlyk, 2009).

When establishing the causes of heterogeneity and instability of neurohumoral regulation of heart rhythm in children and adolescents, researchers point to the complexity and multifactoriness of this phenomenon, which is influenced by: (i) constitutional-genetic imbalance of the mechanisms of regulation of physiological functions; (ii) critical periods of functional maturation of the autonomic nervous system in ontogenesis, causing the tension of adaptive mechanisms (Nikolayev, 2001; Polina & Krivitsky, 2016; Sitdikov & Sheykhelislamova, 2008). In addition, the features of children's adaptation at different stages of ontogenesis are determined by sex and age factors (Bogdan, 2000; Shlyk, 2009).

Taking into account these effects, we studied the adaptive processes of healthy children in age groups of 11-16 years using the diagnosis of heart rate variability. Children were influenced by different factors of the educational environment while being at school. We focused on the state of their adaptive mechanisms at different stages of ontogeny. We also would like to note that the research was approved by the Human Research Ethics Committee of the Toliatti State University (Toliatti, Russia) in 2015.

MATERIALS AND METHODS

The paper has a goal to study adaptive mechanisms the healthy children have at the age of 11-16 years at various stages of ontogenesis by the method of heart rate variability. The study had the following objectives: (i) to carry out a typological diagnosis of the regulation of the cardiovascular system (CVS) by departments of the nervous system (NS) in different age groups of students at the stage of the ascertaining pedagogical experiment (PE); (ii) to conduct physical education lessons for the schoolchildren being assigned to two comparison groups (11-13 and 14-16 years) in accordance with the typological features of regulation of the cardiovascular system from the central nervous system and the autonomic nervous system; and, finally, (iii) to compare dynamics of heart rate variability in the comparison group and the main group in order to determine effectiveness of the typological approach in physical education of schoolchildren.

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Participants
We conducted research on the basis of School No. 90 in the city Toliatti, Russia. Twenty-five schoolchildren of both sexes were examined in each group of students aged 11-16 years. The total number of students being examined was 300. The main criterion for the selection of children for participation in the study was their health. Children were examined by doctors, and, according to the results of medical examination, all schoolchildren were assigned to the I group of health (i.e. not having diseases). Thus, they are practically healthy, rarely sick children, who have normal physical development. According to the age periodization of individual development (ontogeny) adopted in the Russian Federation, 11-12-year-old boys and 11-year-old girls are considered to be in the period of the second childhood, boys of 13-16 years and girls of 12-15 years are in the period of adolescence, and girls of 16 years are in their early youthful age (Baranova, 2006, Yampolskaya, 2000, Yasyukova, 2016).

Measures
For the evaluation of cardiointervalograms and analysis of heart rate variability we used the hardware-software complex "Varicard 2.51", which provides all the main methods for analysing heart rate variability (such as statistical analysis, variation pulsometry, autocorrelation and spectral analysis, etc.). "Varicard 2.51" allows calculating up to 40 different parameters recommended by both Russian and international diagnostic standards (Baevsky, 2001; Semenov, 2014).

The following parameters of heart rate variability were used in our study: (i) R-R – mean interval duration; (ii) HR – heart rate; (iii) MxDMn – the range of cardio intervals; (iv) RMSSD – activity of the parasympathetic link of autonomic regulation; (v) – the stress index Si that characterizes the degree of tension of regulatory systems; (vi) VLF characterizes hyperactive or energy deficient state of the organism (Baevsky, 2001; Salivon & Polina, 2002; Shlyk, 2009).

"Varicard 2.51" solves the problem of assessing adaptive capabilities of the organism based on the analysis of HRV electrocardiograms, allowing for fully automatic decoding of its amplitude-time parameters and automatically providing conclusions. In addition, this device is widely used for conducting mass surveys on adaptive capabilities of the population, including children (Bets, 1999; Bogdan, 2000; Nikolayev, 2001).

To determine health indicators and functional capabilities of schoolchildren's organism in the process of physical education, we examined their functional indicators (integral indices). They are also widely used in mass surveys. The express assessment of schoolchildren's physical health includes five functional indices (Quetelet, Robinson, Skibinsky, Shapovalova, and Ruffier), which all together assess the level of physical development and deviations in health (Polyakov, 2002).

To calculate the indices, we collected the following information: (i) body length and body weight; (ii) vital capacity of the lungs; (iii) heart rate (HR); (iv) blood pressure (BP); (v) breath holding time for inspiration (also known as the Stange test); (vi) the Ruffier functional test; and (vii) the Shapovalova capacity index. At the same time, we determined the levels of schoolchildren's physical health in the following grades: low, below average, average, above average, and high. The following indicators of deviations in health were used: (i) arterial pressure (arterial hypertension, hypotension); (ii) body weight (obesity, body weight deficiency); and (iii) body length (high, short stature) (Polyakov, 2002; Salivon & Polina, 2002).

Thus, we calculated the following indicators: (i) the weight-growth index - Quetelet index, characterizing the degree of physical development; (ii) the double product – Robinson index, characterizing the cardiovascular system regulation and the degree of economization of its operating parameters at rest; (iii) the Skibinsky index, characterizing the functional capabilities of the respiratory system, as well as body's resistance to hypoxia and volitional qualities; (iv) the Shapovalova capacity index, characterizing the development of power and speed endurance of back muscles and abdominal press; and (v) the Ruffier index, characterizing the response of the cardiovascular system to standard physical activity.

Procedures

All measurements were carried out by the authors of this publication. Thus, the data obtained are 100% original. Using an automated computer program and on the basis of sex and age tables of formalized index estimates, each index is given a score in points (from 1 to 5). Then, the total score is calculated, according to which the level of students' physical health is determined. The overall quantitative assessment of physical health in scores allows a student to be assigned to a particular functional class: (i) low (5-9 points); (ii) below average (10-13); (iii) average (14-18); (iv) above average (19-22); and (v) high (23-25) (Polyakov, 2002).

The study was carried out in the form of a pedagogical experiment. At the ascertaining stage of this experiment, we made initial measurements. Then, at the forming stage, all children physically exercised in the age groups of 11-12 years, 13-14 years, and 15-16 years. They had a number of physical exercises selected according to the types of regulatory influences on the cardiovascular system from the autonomic nervous system. The following groups were identified according to the types of regulation:

- MOPCR (I group) – moderate prevalence of central regulation;
- MAPCR (II group) – marked predominance of central regulation;
- MOPAR (III group) – moderate predominance of autonomous regulation;
- MPAR (IV group) – marked predominance of autonomous regulation.

After completing the formative stage of the pedagogical experiment, repeated measurements of the indicators in the groups of schoolchildren were made under the same conditions.

Analysis

We examined the dynamics of changes in the schoolchildren of 11-16 years on the basis of the six parameters of heart rate variability (R-R, HR, MxDMn, RMSSD, Si, and VLF) in order to analyse how complex changes in the functional systems of the body and neurohormonal mechanisms of its regulation can lead to changes in the processes of adaptation to physical exercises. Then we used the method of Spearman (Spivak, 2014) to explore the relationships existing between the integral indices of physical development and the parameters of heart rate variability.

RESULTS

We studied the processes of adaptation to physical exercises in physical education classes for groups of schoolchildren differentiated by age (11, 12, 13, 14, 15, and 16 years) and sex (male, female). The study was conducted in a large industrial city of Toliatti, Russia.

Results of the ascertaining stage of the pedagogical experiment are presented in Tables 1-2 and Figures 1-2.

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Table 1. Sex and age differences in heart rate variability in male schoolchildren aged 11-16 at the ascertaining stage of the pedagogical experiment

Age / Indicator	HR	R-R	MxDMn	RMSSD	Si	VLF
11 years	83,4±2,4	750,5±28,6	294,3±2,4	38,4±3,4	140,4±25,2	210,4±23,1
12 years	81,9±2,8	741,9±31,4	304,9±5,4	36,9±2,7	147,2±26,3	207,1±19,2
13 years	80,1±1,1	757,6±27,8	299,9±6,1	56,6±3,6	146,4±25,2	435,5±26,1
14 years	76,4±1,9	802,5±25,3	301,5±4,9	64,5±3,7	140±21,9	546,5±33,4
15 years	74±2,3	837,8±29,1	314,8±3,5	63,5±4,1	128,8±18,4	527±35,6
16 years	74,4±1,4	805,6±32,3	352,3±6,2	59±5,3	135,4±15,2	570,3±41,5

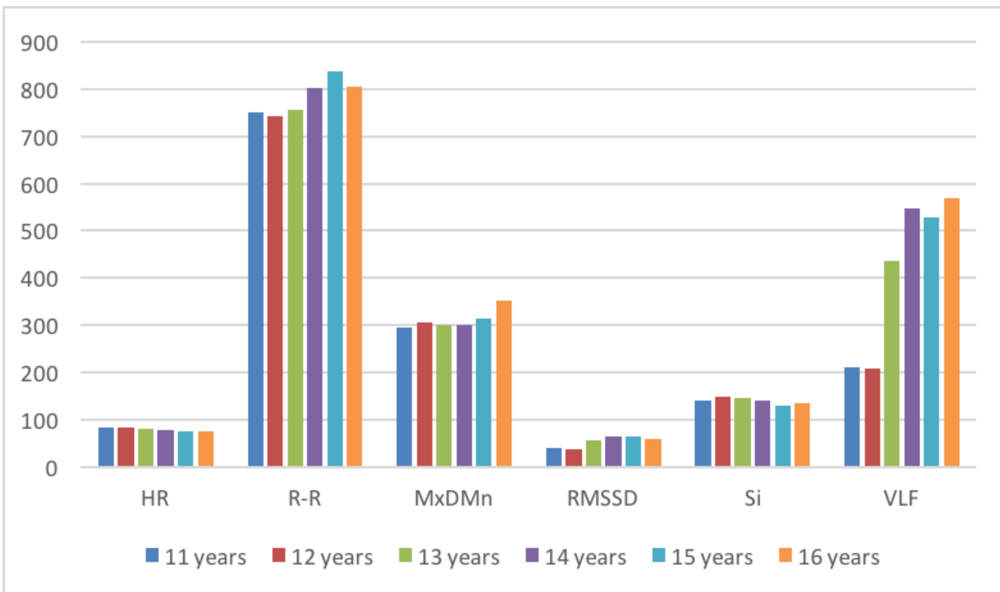

Figure 1. Parameters of heart rate variability in male schoolchildren aged 11-16 at the ascertaining stage of the pedagogical experiment

Table 2. Sex and age differences in heart rate variability in female schoolgirls aged 11-16 years old at the ascertaining stage of the pedagogical experiment

Age / Indicator	HR	R-R	MxDMn	RMSSD	Si	VLF
11 years	83,1±2,8	748,4±31,2	290,5±5,9	40,1±4,6	141,3±23,1	230,4±25,3
12 years	80,9±1,9	750,8±33,4	291,5±4,6	59,5±5,3	146,5±22,4	392±39,1
13 years	81,8±2,3	745,5±29,7	305±7,2	61,8±5,1	142,5±19,7	620,8±54,3
14 years	76,5±1,7	790±35,1	300,3±7,5	57,5±4,9	151±25,1	511,5±48,2
15 years	76±1,5	790±33,7	251,3±4,3	45,5±3,7	160,5±33,4	614,8±51,3
16 years	75,3±1,9	780,4±32,4	248,5±3,5	43,2±5,4	169,4±29,5	610,5±39,4

** P<0,05*

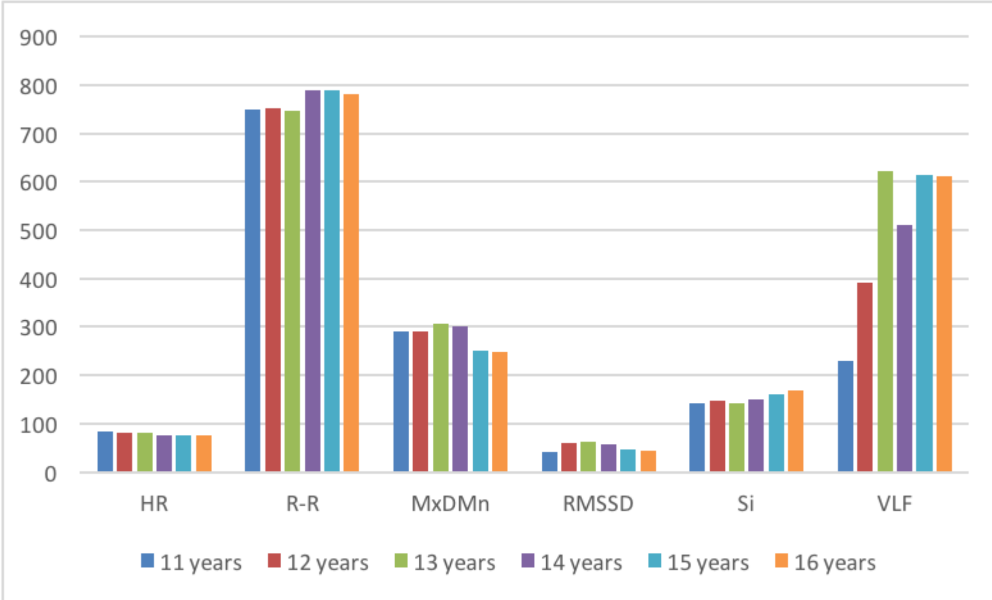

Figure 2. Parameters of heart rate variability in schoolgirls female aged 11-16 years old at the ascertaining stage of the pedagogical experiment

The data from Table 1 and Figure 1 allow one to trace the age-related dynamics of heart rate variability in boys (11-12 years) and adolescents (13-16 years), most of which increase as the children grow up, with the exception of heart rate and stress index. The value of the stress index (Si) does not show significant age dynamics, whereas the RMSSD index increases almost twofold (by 43%) at the age of 13-16 as children grow up. The increase in the mean duration of the cardiointervals (R-R index) by 7.5% also indicates an increase in the functions of the heart muscle as the boys grow up. The energy deficit (VLF) of boys' cardiovascular system begins to increase at age 13, but this is insignificant compared to girls of this age.

To determine the degree of influence sexual dimorphism has on the age-related dynamics of the cardiovascular system, we examined girls of the same age groups. The data are presented in Figure 2 and Table 2. Regarding the dynamics of heart rate, the results of girls do not reveal gender-related differences in the stabilization of contractile functions of the heart muscle, but the stress index (Si) shows noticeable differences related to the sex factor. Girls of pubertal age (15-16 years) have indicators of stress-index increasing by 18%. Age changes in the link of parasympathetic regulation (RMSSD index) have different dynamics in girls, increasing by 45-50% at the age of 12-14. Nevertheless, they fall in 15-16 years practically to the level of 11-year-olds, whereas similar changes are maintained in boys from 13 to 16 years. The indicator of the length of the cardiointervals (index R-R) does not show the age dynamics, and the spread of cardiointervals in girls had a dynamic opposite to that in boys, decreasing by 20% when growing up. The energy deficit (VLF index) at the age of 13-16 increases by 61%, and the growth of the indicator starts 3 years earlier than in boys. Thus, we determined the dynamics of heart rate variability in healthy schoolchildren, showing the dependence on the age and sex of schoolchildren.

Measurements at the forming stage of the pedagogical experiment were made after classes with schoolchildren of all sex and age groups according to physical education programs selected in accordance with the types of regulation of the cardiovascular system. The results obtained during this repeated examination of students are shown in Table 3 and Figure 3.

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Table 3. Sex and age differences in heart rate variability in male schoolchildren aged 11-16 old at the formative stage of the pedagogical experiment

Age / Indicator	HR	R-R	MxDMn	RMSSD	Si	VLF
11 years	82,1±2,4	744,1±33,4	284,1±4,3	37,3±3,8	135,3±19,4	210±21,7
12 years	80,4±1,9	751,8±37,5	314,7±5,2*	35,7±3,1	150,3±25,7	217±18,5*
13 years	79,6±0,5	757±41,2	289,7±3,9	59±4,5	136,7±21,4	335,5±34,6
14 years	76,7±2,4	812±44,3	311,7±3,3	54,3±6,1	124±18,5*	441,3±37,1
15 years	73,8±1,5	847,9±41,7	324,3±3,7	65,1±5,9	108,3±32,5	427±32,4
16 years	74±1,8	835,5±45,4	342,3±3,1*	59±5,3	115,4±24,7*	470,3±43,9*

** P<0,05*

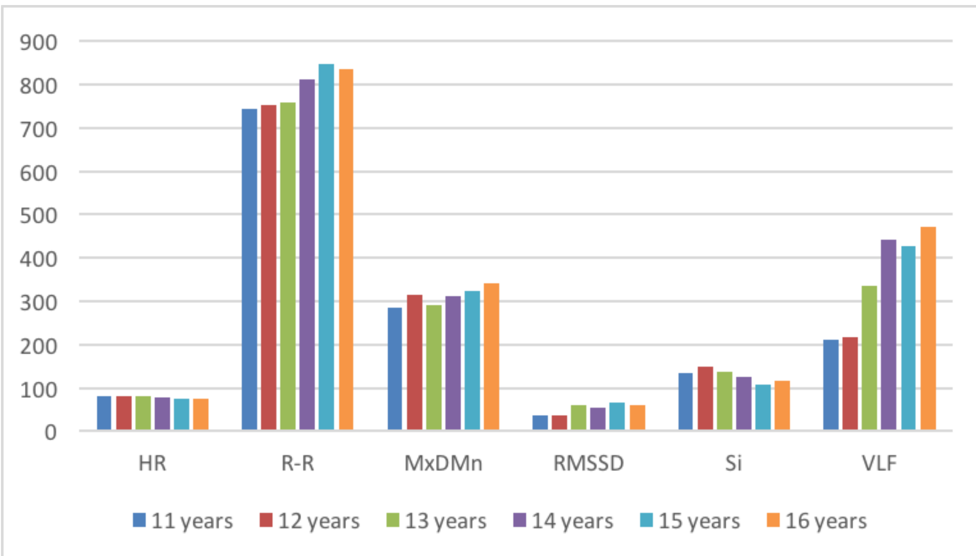

Figure 3. Parameters of heart rate variability in male schoolchildren aged 11-16 years old at the formative stage of the pedagogical experiment

The duration of the cardio intervals (R-R index), heart rate, and the RMSSD index in boys do not differ after physical education lessons from the findings obtained at the ascertaining stage, which is an indicator showing that the selected load was correct. In the older age group of 15-16 years, the stress index (Si) decreases by 20%. Under the influence of physical training, the energy deficit (VLF) of the heart contractile function in adolescents of 14-16 years decreases by 11% compared with the ascertaining stage, at which the index increased by 65% compared to the group of 11-year-olds.

To study the influence of the sex factor on adaptation to physical exertion, we examined girls after they had physical exercises in physical education classes, which were selected in accordance with the types of regulation of the cardiovascular system. The results are shown in Table 4 and Figure 4.

Table 4. Sex and age differences in heart rate variability in female schoolgirls 11-16 in the formative stage of the pedagogical experiment

Age / Indicator	HR	R-R	MxDMn	RMSSD	Si	VLF
11 years	83±1,2	750,1±29,4	280,4±3,1	39,7±3,1	145,7±18,4	220,1±23,1
12 years	82,3±1,9	760,4±35,5	299,1±4,7	58,7±4,6	136,1±15,1*	382±29,7
13 years	81±0,9	755,3±28,7	315±4,9	61±5,4	140,1±19,3	410,8±31,4*
14 years	77,3±1,7	796,3±39,4	300,3±5,4	57,5±4,1	140±20,4	521,1±42,5
15 years	75±2,1	788,4±36,8	259,1±4,3*	43,7±3,5	155,±23,5	570,4±24,6*
16 years	74,8±1,3	790,3±35,3	288,3±6,1*	45,4±2,9	140,4±16,3*	580,5±51,3

** P<0,05*

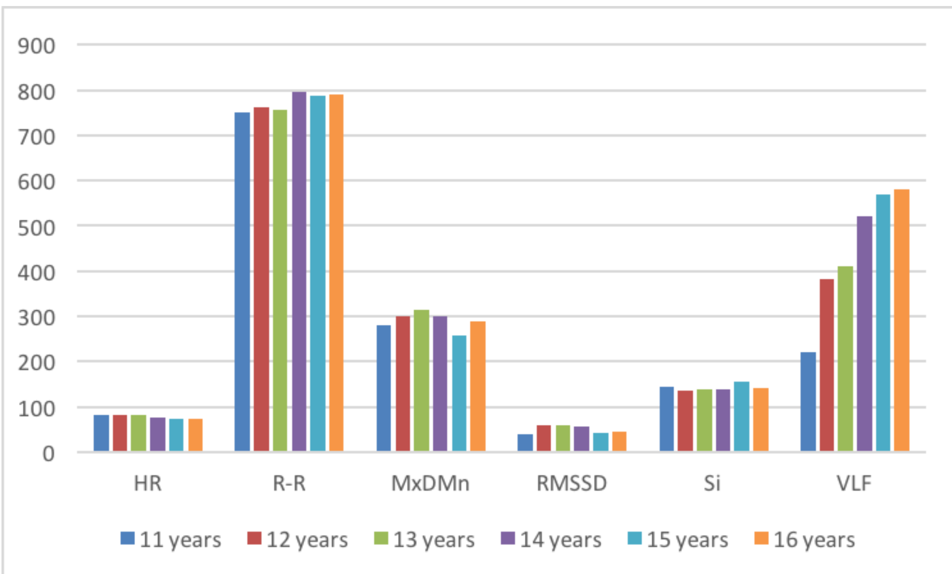

Figure 4. Parameters of heart rate variability in schoolgirls of 11-16 years old at the formative stage of the pedagogical experiment

The dynamics of age indices of the frequency of heart rate, the duration of cardio interval (R-R), the spread of cardio intervals, and the activity of the parasympathetic regulator of cardiovascular system in girls significantly do not change due to physical activity. The stress index (Si) in groups of girls of pubertal age (15-16 years old) decreases by 11% after physical education lessons, and the energy deficit condition of the heart (VLF index) decreases by 7% compared to the indicators of these groups at the ascertaining stage.

Based on the measurement of the integral indices of physical development, we calculate their correlation relationships using the Spearman method (Spivak, 2014) with the indices of heart rate variability (Table 5). The analysis shows reliable positive relationships between the Quetelet index and the stress index (Si), as an indicator of adaptation mechanisms in the pubertal period, only in the group of 16-year-olds.

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Table 5. Spearmen's correlation of heart rate variability and physical development indexes in a group of 16-year-old boys

N=25	Quetelet	Skibinsky	Si	VLF
Quetelet	1	-0,11	.51*	0,213
Skibinsky	-0,011	1	0,131	-0,026
Si	.51*	0,131	1	-.702**
VLF	0,213	-0,026	-.702**	1

** Correlation is significant at .05 (two-tailed)*
*** Correlation is significant at .01 (two-tailed)*

Table 6. Spearmen's correlation of heart rate variability and physical development indices in a group of 14-year-old girls

N=25	Quetelet	Skibinsky	Si	VLF
Quetelet	1	0,37	.53*	-0,178
Skibinsky	0,37	1	-0,261	.545*
Si	.53*	-0,261	1	-.494*
VLF	-0,178	.545*	.494*	1

** Correlation is significant at .05 (two-tailed)*

Table 6 shows data on the correlation of heart rate variability indices and physical development indices in 14-year-old girls. There is a reliable positive age-related relationship between the Quetelet index and the stress index (Si) in girls from the age of 14. The analysis also shows a reliable relationship between the energy deficiency (VLF) and the Skibinsky index, characterizing the functional capabilities of the respiratory system, resistance to hypoxia.

DISCUSSION

Over the course of our research, we paid special attention to the girls during physical education lessons (Fedina et al., 2011). The age range of the girls' groups under study coincides with the onset of puberty, which occurs 1.5-2 years later in boys (Nikolayev, 2001). In this critical period of ontogeny, the increased excitability of the nervous and psycho-emotional systems, their reactivity and instability to neuropsychiatric stresses are observed (Salivon & Polina, 2002; Sitdikov & Sheykhelislamova, 2008).

These provisions are confirmed by the obtained data on the diagnosis of heart rate variability in the pedagogical experiment in different sex and age groups of schoolchildren. All examined children were practically healthy, therefore their development and indices of heart rate variability can be considered appropriate to normogenes (Nikolayev, 2001; Shlyk, 2009).

The data in Figure 1 and Table 1 show the sex-adjusted age-related changes in in heart rate variability in boys (11-12 years old) and adolescents (13-16 years old), which increase in adulthood, except for the heart rate and stress index. Reduction of the heart rate by 9-10% as it grows is a natural phenomenon, which is due the stabilization of regulatory and functional capabilities of the cardiovascular system. The energy deficit (VLF) of boys' cardiovascular system begins to increase at age 13, but it increases by 65% at the age of 16, which is associated with the tension of the mechanisms of regulation of the functions of the cardiovascular system during neuroendocrine changes in the body and is also manifested in a 14% increase in the spread of cardiointervals.

The influence of sexual dimorphism on the age-related dynamics of neurocardial regulation of cardiovascular functions can be revealed in comparative studies in different age groups of boys and girls. It was found that the girls of puberty age (15-16 years old) have the stress index being increased by 18%. In our opinion, this indicates certain tensions of adaptation mechanisms, which does not occur in boys of this age perhaps because of a later onset of puberty. The energy deficit (VLF index) at the age of 13-16 increases by 61%, and the growth of the indicator starts 3 years earlier than in boys, which indicates an earlier puberty in girls for 2-3 years. It can be assumed that the revealed differences in the dynamics of the VLF index are determined by the factor of sex and are caused by the stress mechanisms of the regulation of cardiovascular functions in girls and, consequently, by the adaptive potential of neuroendocrine changes in the organism during puberty. The validity of the assumptions is confirmed by data on the increase in stress hormones (adrenocorticotropic hormone, cortisol) in females with the onset of active phases of the menstrual cycle (Fedina et al., 2011), which indicates the tension of adaptive mechanisms in females.

Reduction of the stress index (Si) and the energy deficit (VFL index) in groups of girls of pubertal age (15-16 years old) may be due to an increase in the adaptive potential of girls. These changes are 2 times lower than in male adolescents of 15-16 years, which indicates a less noticeable reactivity of the female organism at pubertal age to the training effect of physical activity. Only a group of 16-year-old male adolescents has significant positive correlations of the Quetelet index and the stress index (Si). This suggests that the processes of puberty begin when the growing organism reaches certain mass-growth parameters. The found correlation between the Quetelet index and the stress index (Si) as well as between the energy deficiency (VLF) and the Skibinsky index in girls from the age of 14 also speaks in favour of our assumptions. The onset of puberty in girls (2 years earlier than in adolescent males) requires strengthening of the biological adaptation mechanisms, which are, in turn, accompanied by an intensification of the cardiovascular and cardiorespiratory system, providing adaptation of the child's organism to environmental factors.

PRACTICAL IMPLICATIONS

This research substantiates the need for an individual typological approach in physical education of schoolchildren. Their physical activity should be evaluated on the basis of neurophysiological regulation of the cardiovascular system functions while taking into account certain features of adaptation, which can have a positive effect on the effectiveness of physical education in schools.

CONCLUSIONS

1. Relevance of the research on the problems of physiological adaptation with respect to age, reflected in the growing number of published articles in recent years, allows the authors of the article to state that age adaptology is forming as a new integral direction of physiology.
2. The study shows that the age-related dynamics of heart rate variability in healthy schoolchildren are determined by sex.
3. The activity of the parasympathetic regulation link (RMSSD index) in boys aged 13-16 years increases by 2 times (namely, by 43%). An increase of 45-50% in girls occurs at the age of 12-14 years, falling to the level of 11-year-old girls in 15-16 years.
4. The stress index (Si) has no noticeable age-related dynamics in boys. The index increases by 18% in girls aged 15-16 years as an indicator of adaptive stress at the onset of puberty in girls.

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5. The energy deficit (VLF-index) of boys' cardiovascular system begins to increase at the age of 13, reaching 65% at the age of 16. The increase of the VLF-index by 61% occurs in girls at the age of 13-16, i.e. 3 years earlier than in boys because of earlier puberty.
6. In the course of boys' adaptation to the optimally selected physical activity in physical education lessons, we observe a decrease in the stress index (Si) by 20%, which indicates an increase in their adaptive potential. Lowering the stress index (Si) was 2 times smaller in girls of 15-16 years probably because of the less noticeable reaction from the cardiovascular system at the pubertal age on physical training.
7. The correlation of the Quetelet index is established in boys from the age of 16, and this relationship is manifested in girls from the age of 14 and is supplemented by reliable links of the cardiovascular energy deficiency parameter with the Skibin index. This indicates the activation of adaptation mechanisms during puberty 2 years earlier in girls than in boys.

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