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A Shift of the Parameters of the Cardiovascular System in Adolescents during the Period from 2004 to 2020 as a Result of Modification of Educational Environment

Nataliya B. Pankova, Mikhail Yu. Karganov*

Laboratory of Physical, Chemical and Ecological Pathophysiology, Institute of General Pathology and Pathophysiology, Moscow, Russia

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Abstract The purpose of our study was to search for possible changes in the parameters of the cardiovascular system in adolescents during the period from 2004 to 2020 against the background of the introduction of digital technologies into the educational environment. Methods: A comparative analysis of the parameters of the cardiovascular system in female and male adolescents aged from 13.9 to 15.4 years was carried out (57 adolescents in 2004 and 53 adolescents in 2020). We used a spiroartheriocardiorythmograph allowing recording of heart rate (HR) and blood pressure (BP) and spectral parameters of HR variability and variability of systolic (sBP) and diastolic (dBP) BP. The parameters were recorded at rest in the sitting position for over two min. All studies were performed during school hours in February-March. Results: An increase in the mean sBP values and an increase in the proportion of adolescents with BP in the "hypertension" range to 55% were found in 2020. The total power of HR variability spectrum remained constant, while the relative power of the LF range increased and the absolute power of the VLF range tended to decrease. In the sBP variability spectrum, an increase in the total power and all its ranges was detected, but the relative power of the LF range decreased. In the dBP variability spectrum, the absolute power of the VLF range decreased, while the total power remained constant. No changes in the stress index and alpha index were detected. The dynamics of the parameters in male and female adolescents were similar. Conclusion: These findings indicate significant shifts in the parameters of the cardiovascular system in adolescents from 2004 to 2020 recorded during school hours analysis of the parameters of heart rate and BP variability reflecting the mechanisms of regulation of the cardiovascular system, suggests that the identified shifts were caused by psycho-emotional stress. We associate this state with the use of digital educational technologies. This trend requires the close attention of school health professionals. It would be expedient to establish the practice of BP measurements at school and share hygienic recommendations on working with digital technologies for students and their parents.

Keywords Cardiovascular System, Blood Pressure, Heart Rhythm Variability, Blood Pressure Variability, Adolescents, Educational Environment

1. Introduction

In recent years, significant changes in the human social environment are associated with the development of computers and total digitalization. The educational environment that largely determines the living space and takes much time in adolescents has been also modified by these processes. Modern individuals have to adapt to new living conditions. This makes it easier to perform routine tasks, gives new opportunities for personal development, but also poses threats to health.

According to the All-Russian Society for the Development of School and University Medicine and Health, a member of the European Union of School and University Health and Medicine (EUSUHM), the risks to schoolchildren's health in modern life include: 1) hygienically unsatisfactory conditions of education and upbringing; 2) questionable pedagogical technologies; 3) digitalization of the children's living environment; 4) hypokinesia; 5) unhealthy diet; 6) health-risk behavior; 7) ineffective organization of medical support in the educational process [1]. These provisions are close to the position of EUSUHM [2]. From the viewpoint of clinical medicine, most of these environmental factors have a pronounced effect on the cardiovascular system. For instance, non-compliance with hygienic requirements for the organization of the educational process contributes to psychological stress, which is an important risk factor for essential hypertension [3].Violations of daily round and poor sleep can be associated with multisystem hyperactivity, including sympathetic hyperactivity leading to the development of vascular pathology [4]. An unhealthy diet is often the cause of metabolic disorders in schoolchildren [5] that are also a risk factor for cardiovascular diseases [6]. However, the digitalization of education is the greatest concern.

The development of digital technologies has created many temptations for adolescents, the most popular of which are video games, social media, and Internet surfing. These factors pose potential risks to their health. In 2015, it was shown that the proportion of adolescents with high blood pressure (BP) is higher among active Internet users aged 14-17 years (>2 hours per day) [8]. During a video game lasting longer than 24 min (which is lower than current hygienic standards), 42% of adolescents experience BP rise to a level of "hypertension" [9]. In the educational environment, including homework, the use of digital devices (computers, tablets, interactive whiteboards) exceeds 2 h per day. In the review of 2021 summarizing the results of health examination in schoolchildren, both positive and negative effects of digital educational gadgets, different in technology and context, on the psychophysiological and somatic parameters of health and learning success, including a stressful BP elevation, were described [10].

It should be remembered that computer learning is not really a game: the process of solving logical problems requires much effort, not only cognitive, but also emotional, related to achieving success or failure. For instance, solving arithmetic problems is accompanied by mental stress and stimulation of sympathetic brain centers that activate the cardiovascular system [10]. Working on a computer is accompanied by simultaneous activation of brain structures responsible for psychomotor activity and regulation of its autonomic support, even during game playing,[11] including activation of sympathetic regulation [12]. It is important that not only working on a computer, but also using a smartphone can induce sympathetic activation and BP elevation [13].

Our aim was the search for possible shifts in the parameters of the cardiovascular system in the 8th-grade students (14-15-years-old adolescents) over the period from 2004 to 2020, during the period of active introduction of digital technologies into the educational environment.

2. Materials and Methods

2.1. Participants

The study included the results of the assessment of the cardiovascular system parameters in 110 adolescents, 8th-grade students of two secondary schools located on the outskirts of Moscow (adolescents from one school were surveyed in 2004, from another school in 2020). The general characteristics of the samples are presented in Table 1. The ethnic composition in both cases was mixed, with predominance (85-90%) of the indigenous population (both Russians and representatives of other nationalities, all white race), others lived in Moscow recently, but fell under the same definitions. All studies in both schools were conducted by the authors personally; devices of the same type were used. The analysis includes the results of all adolescents who came to school on the day of the study.

According to medical records, all participants were practically healthy. Usually, we exclude subjects with cardiac arrhythmias from the analysis, but in this case, no adolescents in the surveyed sample had rhythm disturbances.

Table 1. Characteristics of the studied groups

Studied group	N	Mean age [years] (M ± SE)	Age range [years] (min; max)
Females, 2004	30	14.48 ± 0.06	14.1; 15.2
Females, 2020	22	14.50 ± 0.07	14.1; 15.2
Males, 2004	27	14.51 ± 0.06	14.1; 15.2
Males, 2020	31	14.56 ± 0.08	13.9; 15.4

Table 2. Basic parameters of the cardiovascular system

	Indicator value (M ± SE)				Factor "time"		Factor "time × gender"	
	Females		Males		F (df)	P	F (df)	P
	2004	2020	2004	2020				
HR [bpm]	94.3 ± 2.6	88.7 ± 1.9	91.7 ± 3.1	83.3 ± 2.7	6.688 (1, 106)	0.011	0.288 (1, 106)	0.592
sBP [mm Hg]	110.1 ±3.4	133.9 ±3.9 ***	105.9 ±2.4	137.8 ±4.4 ***	54.659 (1, 106)	< 0.001	1.124 (1, 106)	0.291
dBP [mm Hg]	78.6 ±3.3	75.9 ± 1.9	75.6 ±2.2	82.0 ± 2.8	0.469 (1, 106)	0.494	2.724 (1, 106)	0.102

The data are presented as M±SEM. Intergroup differences were calculated by Factorial ANOVA (time × gender). HR – heart rate, sBP – systolic blood pressure, dBP – diastolic blood pressure

*** Statistically significant differences from 2004 (P < 0.001 according to Duncan's Multiple Range Test)

2.2. Instruments

Cardiovascular system parameters were studied using a spiroarteriocardiorhythmograph (INTOKS, St. Petersburg, Russia) allowing simultaneous continuous registration of electrocardiogram (ECG) in standard lead I (with heart rate (HR) variability evaluation), digital BP by photoplethysmography with the evaluation of the variability of systolic (sBP) and diastolic (dBP) BP. Long-term continuous recording of HR and BP indicators, in addition to the maximum, minimum, and mean values, allows assessing spectral parameters of their variability (total power of the spectrum (TP), the absolute and relative power of standard high frequency (HF), low frequency (LF), and very low frequency (VLF) ranges), stress index, and calculated indexes (LF/HF ratio, alpha index). The R-R interval time series were manually checked for the presence of artifacts; spuriously detected or missed R waves were corrected by linear interpolation. Spectral analysis of HRV and BP variability (BPV) was performed using SACR algorithms. For short records (2-5 min), three main frequency ranges are commonly distinguished: very low frequency (VLF, < 0.04 Hz), low frequency (LF, 0.04–0.15 Hz), and high frequency (HF, 0.15–0.4 Hz). The following parameters were analyzed: the absolute total power spectral densities in the range of 0 – 40 Hz (TP) and the power spectral densities in each frequency range ($msec^2$); relative spectral power of these frequency bands (HF%, LF%, VLF%), normalized power LFn (LF / (TP – VLF) and HFn (HF / (TP – VLF), LF / HF ratio. Under conditions of continuous BP measurement, the frequency method was used to determine spontaneous baroreflex sensitivity (BRS): the α-index was defined as the square root of the ratio of the spectral powers of HRV and systolic BP (sBP) within a band of a LF frequency.

2.3. Design of the Experiment

Parameters of the cardiovascular system were recorded in a sitting position for over two minutes. The studies were performed from 9.00 to 12.00 am. In both schools, the survey was performed from late February – early March. In 2020, all measurements were completed before COVID-19 pandemic-related restrictions were imposed and distant learning was started.

2.4. Ethics

Compliance with international (including the Helsinki Declaration as revised in 2013) and Russian laws on the legal and ethical principles of scientific research with human participation was confirmed by the decision of the Ethics Committee of the Institute of General Pathology and Pathophysiology, protocol No. 1, 1/22/2019.

2.5. Statistics

Evaluation of the normality of the obtained data arrays using the Shapiro–Wilk test showed that only participants' age, HR, and BP averaged over the entire registration period met the normality criterion (p>0.05). Hence, intergroup comparisons by these parameters were performed using the Factorial ANOVA (factors "time" and "gender"), followed by the comparison of the means using Duncan's Multiple Range Test; the data in the tables are presented as M±SE. In other cases, intergroup comparisons were performed using Kruskal–Wallis test for multiple comparisons followed by Dunn's multiple comparisons tests; the data in the tables and figures are presented as the median and interquartile range.

In doubtful cases, we calculated the power of the statistical test and conducted pairwise comparisons between male and female adolescents for different test points using the Mann–Whitney U test.

Fisher's exact method (Chi-square (df=1), two-tailed Fisher exact test) was applied for comparison of the frequency parameters (fractions).

3. Results

3.1. Shifts in the Main Parameters of the Cardiovascular System

A comparison of HR values obtained in 2004 and 2020, revealed no significant differences in HR for male and female adolescents separately, but HR for the total sample decreased during this period: F(1, 106)=6.688, P=0.011 for the "time" factor (Table 2). At the same time, sBP values significantly increased in male and female adolescents as well as in the whole sample: F(1, 106)=54.659, P<0.001. dBP did not change during this period in gender subgroups and in the whole sample. At no time points, the differences between male and female adolescents by the above parameters of the cardiovascular system were observed; the interaction between the factors "time" and "gender" was not revealed.

Analysis of the prevalence of different sBP values in terms of "normal BP" (<120 mm Hg), "elevated BP" (121-130 mm Hg), and "hypertension" (>130 mm Hg) according to the recommendations of the European Society of Cardiology (ESC) and European Society of Hypertension (ESH),[14] American Academy of Pediatrics (AAP) and American Heart Association (AHA),[15] [16] as well as current National Clinical Guidelines "Arterial hypertension in children" [17] revealed a significant increase in the proportion of both female and male adolescents with sBP corresponding to"hypertension" range (Chi-square (df=1) 8.28, P=0.004 and Chi-square (df=1) 20.95, P<0.001, respectively) due to a decrease in the proportion of adolescents with sBP corresponding to normal BP range in both cases (Chi-square (df=1) 9.82, P=0.002; Chi-square (df=1) 17.92, P<0.001, respectively) (Fig. 1). The proportion of adolescents with sBP in the "elevated BP" range remained unchanged. It should be noted that even in 2004, the distribution of sBP values did not correspond to the reference distribution of 90% for "normal BP" (below the 90th percentile), 5% for "elevated BP" (from the 90th to the 95th percentile), and 5% for "hypertension" (above the 95th percentile).

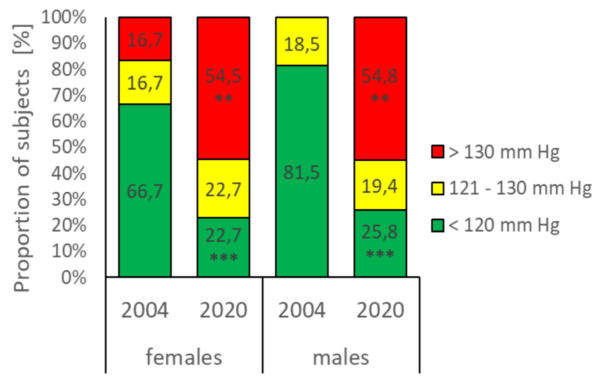

Figure 1. Proportions of different values of systolic blood pressure. Statistically significant differences from 2004 (according to Fisher's exact method): ** P < 0.01, *** P < 0.001

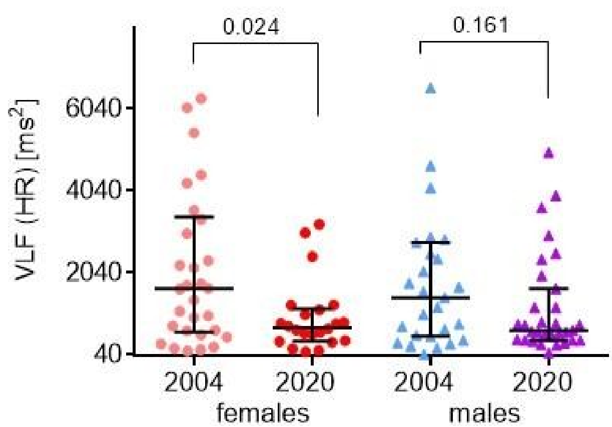

Figure 2. Absolute power (in ms2) of the very low frequencies (VLF) range of heart rate (HR) variability spectrum. The data are presented as Me and IQR with individual values. Statistically significant differences from 2004 are according to Dunn's multiple comparisons

Table 3. Specific data of Column/Row

	Indicator value (Me (Q1; Q3))				H (df)	P
	Females		Males			
	2004	2020	2004	2020		
TP (HR) [ms2]	4800 (2309; 6536)	3.73; 4649	4317 (1606; 9662)	3216 (1867; 5242)	2.781 (3, 110)	0.427
VLF (HR) [ms2]	1652 (598; 3731)	704 (380; 1166)	1439 (488; 2782)	634 (393; 1647)	7.010 (3, 110)	0.072
LF (HR) [ms2]	1142 (340; 2887)	1465 (872; 2375)	871 (349; 1581)	1328 (786; 2352)	4.194 (3, 110)	0.241
HF (HR) [ms2]	1287 (292; 3122)	794 (335; 1615)	304 (170; 912)	680 (201; 2015)	7.036 (3, 110)	0.070
LF (HR)/HF (HR) [c.u.]	0.99 (0.66; 1.89)	1.81 (1.06; 3.92)	1.82 (1.03; 4.99)	1.79 (0.66; 3.27)	7.615 (3, 110)	0.055
Stress-index [c.u.]	167.7 (84.9; 264.9)	134.9 (100.6; 210.9)	120.4 (57.7; 191.5)	117.4 (56.7; 166.5)	2.643 (3, 86)	0.449
TP (sBP) [mm Hg2]	33.58 (12.80; 65.87)	81.70 (42.70; 144.60) **	24.36 (12.94; 57.46)	68.60 (42.70; 155.00) **	22.948 (3, 110)	< 0.001
VLF (sBP) [mm Hg2]	12.15 (3.67; 26.55)	52.80 (21.70; 46.40) **	15.28 (4.88; 48.38)	32.80 (15.80; 93.90)	20.372 (3, 110)	< 0.001
LF (sBP) [mm Hg2]	9.41 (5.56; 19.48)	17.45 (8.80; 44.10)	7.29 (3.35; 16.21)	15.40 (11.50; 49.90) *	8.951 (3, 110)	0.029
HF (sBP) [mm Hg2]	5.28 (2.73; 12.12)	11.50 (5.70; 16.40)	2.98 (0.85; 5.69)	10 (4.80; 24.40) **	26.590 (3, 110)	< 0.001
Alpha-index [ms / mm Hg]	9.4 (6.3; 20.1)	9.0 (6.5; 11.9)	11.7 (5.0; 17.7)	11.5 (6.2; 13.9)	1.258 (3, 110)	0.739
TP (dBP) [mm Hg2]	23.89 (14.91; 49.44)	15.40 (12.40; 26.50)	17.84 (12.60; 68.20)	19.50 (13.10; 60.40)	3.217 (3, 110)	0.359
VLF (dBP) [mm Hg2]	15.02 (7.70; 29.36)	6.80 (3.90; 11.40) ***	29.79 (17.33; 91.38)	10.30 (5.70 (33.20) ***	26.579 (3, 110)	< 0.001
LF (dBP) [mm Hg2]	6.62 (4.02; 8.86)	6.20 (4.60; 10.50)	4.28 (3.09; 14.47)	7.80 (4.00; 11.30)	1.537 (3, 110)	0.673
HF (dBP) [mm Hg2]	1.95 (0.20; 4.79)	1.95 (1.20; 2.70)	2.41 (1.09; 3.30)	2.40 (1.80; 5.10)	4.210 (3, 110)	0.239

3.2. Changes in Spectral Parameters of HR, sBP, dBP Variability

Analysis of the spectral parameters of HR variability in absolute values (ms2) revealed no statistically significant changes in the total power (TP) of HR spectrum (HR), LF (HR) range, and stress index within the subgroups of female and male adolescents over the studied period (Table 3). The general tendency (P=0.072) to a decrease in the spectral power of the VLF (HR) range was confirmed by pairwise comparisons using the Mann–Whitney U test in female participants (U=209.0, P=0.024, at P=0.181 for Dunn's multiple comparisons test) and not confirmed in male adolescents (U=328.0, P=0.161, at P=0.855 for Dunn's multiple comparisons test) (Fig. 2). For this parameter, we calculated the power of the statistical test using the 2-Way ANOVA algorithm: Sigma 8324, RMSSE when comparing groups at different time points 0.6413, when comparing by gender 0.1929, the interaction of factors 0.1241; the power of the test was 0.98, 0.24, and 0.20, respectively. Hence, the quantitative composition of the groups and the characteristics of the sample allow us to make a reasonable conclusion on the influence of the time factor on VLF (HR) value, though the effect was quantitatively assessed using nonparametric statistical tests in accordance with the results of sample testing for normality of distribution.

Pairwise comparisons using Dunn's multiple comparisons test or Mann–Whitney U test did not confirm the differences in HF (HR) (P=0.070) and the LF/HF ratio (P=0.055) that were revealed at the level of tendency. However, we found an increase in the relative (in %) power of the LF (HR) range (Fig. 3) in both female (Mean rank diff. –37.93, P<0.001) and male adolescents (Mean rank diff. –22.40, P=0.045).

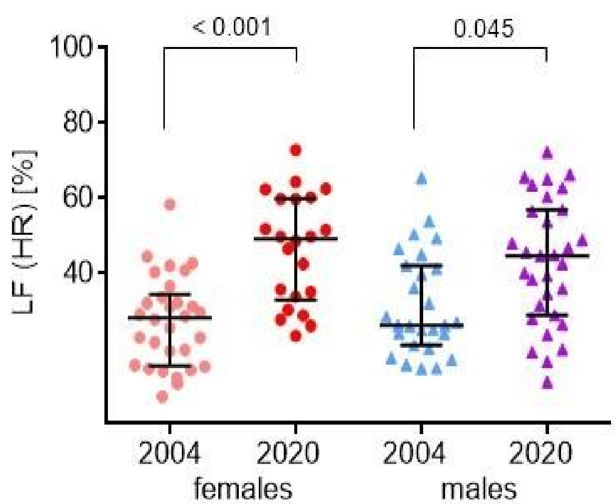

Figure 3. Relative power (in %) of the low-frequencies (LF) range of heart rate (HR) variability spectrum. Other explanations as in Fig. 2

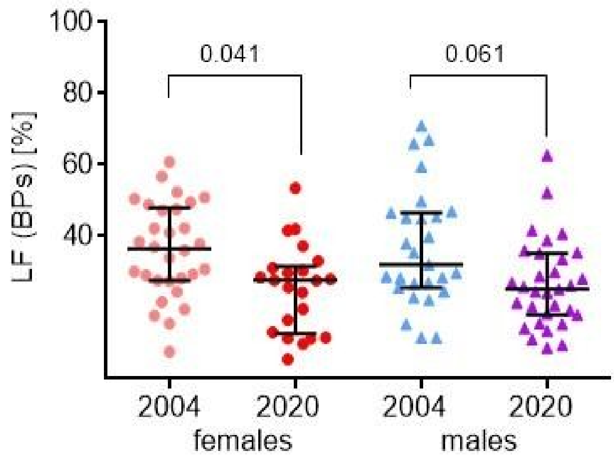

Figure 4. Relative power (in %) of the low-frequencies (LF) range of the systolic blood pressure (sBP) variability spectrum. Other explanations as in Fig. 2

In the sBP variability spectrum, significant changes were demonstrated even for absolute values (mm Hg) (Table 3). Thus, we observed an increase in the total spectral power of TP (sBP) in the subgroups of male and female adolescents (for the whole sample, H (3, 110) 22.948, P<0.001) due to an increase in the power of all analyzed parameters. In female adolescents, the increase in the VLF (sBP) was significant (for the whole sample H (3, 110) 20.372, P<0.001), while in male adolescents this increase did not reach the level of statistical significance. We also found a significant increase in the LF (sBP) (for the whole sample H (3, 110) 8,951, P=0.029) and HF (sBP) (H (3, 110) 26,590 P<0.001) in male adolescents; in female subjects the shifts were similar, but did not reach the level of statistical significance. Moreover, we found a significant decrease in the relative power (in %) of LF (sBP) in female participants (Mean rank diff. 24.16, P=0.041) and a tendency to a decrease in this parameter in male adolescents (Mean rank diff. 21.50, P=0.061) (Fig. 4). It should be noted that we found no changes in the alpha index, that is calculated on the basis of spectral indices of HR and sBP variability (H (3, 110) 1.258, P=0.739).

In the spectrum of dBP variability (in absolute values; mm Hg), only a decrease in the spectral power in the VLF (dBP) was detected in both male and female adolescents (for the whole sample H (3, 110) 26.579, P<0.001) (Table 3). No redistribution of relative (%) parameters in the dBP variability spectrum was found.

4. Discussion

Until 2017, the 95th percentile of the sex and age sample was used as the threshold of elevated BP in the pediatric population, i.e., the proportion of children with elevated BP was presumed to be ~5%. Roughly the same values were reported in 1982 in Croatia (945 boys and 980 girls aged 6-17 years) – 3.1% for sBP and 2.9% for the dBP,[18] in 2005-2006 in Switzerland (2621 boys, 2586 girls, mean age 12.3±0.5 years) – 2.2%,[19] in 2003-2008 in Russia (1300 grade 8-11 students, 14-17 years) – 3.7%.[20] At the same time, pediatricians were very reluctant to diagnose "hypertension" in children and insisted on prolonged observation, repeated measurements, and the search for clinical signs characteristic of hypertension in adults.[18,19]

In 2017, the thresholds of normal BP were more strictly defined for both adults and children. Thus, according to the new recommendations of specialized European and American professional communities, [14,15] the boundary between normal and elevated BP in children remained at the 90th percentile of the parameter distribution in the corresponding sex and age sample, while the boundary between elevated BP and hypertension is the 95th percentile. However, for adolescents aged 13 years and older, adult BP thresholds were recommended: 120/80 mm Hg for the upper limit of normal BP and 130/80 mm Hg for the boundary between elevated BP and hypertension.[21] Studies conducted in the USA [22] showed that when assessing BP according to the new recommendations, the prevalence of hypertension in children and adolescents (22,224 examinations, 10-17 years old) remained at the level of 2-4%, because the criterion of hypertension remained the same (BP above the 95th percentile). However, the proportion of individuals with elevated BP increased to 16%.

In our study, principles of BP ranking corresponding to the latest recommendations of specialized professional communities were applied. It turned out that the proportion of adolescents with elevated BP even in 2004 exceeded the recommended proportions and the data obtained by colleagues.[22] We emphasize that our results cannot be regarded as parameters of the prevalence of hypertension in the adolescent population in the medical aspect, because verification of the medical diagnosis of "hypertension" or "high BP" requires standardized medical procedure according to the recommendations of specialized professional associations. In our study, all measurements were carried out during school hours and reflect the current state of the adolescent's body under the influence of a stressful factor (learning). Changes in the parameters of the cardiovascular system in response to an environmental factor are not a pathology; on the contrary, they reflect adaptation processes in the body, e.g. HR and BP elevation during physical activity.

We can see that in 2004, the educational process was not indifferent to the adolescent's organism and was accompanied by BP elevation in some of them. By 2020, the structure of the sample changed significantly, with a dramatic increase in the proportion of male and female adolescents with hypertension and a parallel increase in the mean sBP values. As measurements of the cardiovascular system parameters were carried out in the same geographic location in the absence of ecological disasters and socio-economic shocks during the observation period, we are convinced that these shifts are driven by changes in the social environment, and probably first of all, by its total digitalization. This is seen from the results of studies on the influence of computer games [8] and smartphones [13] on the probability of developing adolescent hypertension, as well as evidence of a high prevalence of hypertension and prehypertension among young software professionals [23].

In our study, the cardiovascular system parameters were recorded for two minutes, which is less than the classical recommendations (five minutes). This was dictated by the conditions for our survey (during school hours). We understand that such short records reduce the reliability of the obtained data. We relied on the results of comparative studies of different durations of ECG recording that confirmed the fundamental possibility of such an approach [24] and the possibility of analyzing all three significant ranges of the variability spectrum (VLF, LF and HF) on two-min records [25]. In turn, the analysis of spectral parameters makes it possible to propose the mechanisms of formation of the identified shifts in the cardiovascular system.

In our study, analysis of HR variability revealed an increase in the relative power of LF (HR) range. In current recommendations for assessing HR variability (for example, [25]), it is accepted that the power of the LF range reflects baroreflex influences and the level of sympathetic activity in the regulation of cardiac activity. As the alpha index, a calculated parameter reflecting the sensitivity of spontaneous arterial baroreflex, [26] turned out to be unchanged, we assume that the increase in the relative power of the LF (HR) range was determined by increased sympathetic influences on HR. According to modern data, rhythmic fluctuations of the LF (HR) range are characteristic of both the bulbar department of the sympathetic system (and are the result of the activity of the central nervous pacemaker) [27] and other links of this system [28].

The sympathetic nervous system is not only involved in HR regulation, but also plays a key role in the long-term BP regulation through the ability of the central nervous system to integrate neurohumoral signals and differentially regulate sympathetic neural input to specific organs [29]. Therefore, BP elevation in adolescents during the observation period accompanied by an increase in the total spectrum variability power due to intensification of all spectral ranges was logical, though quantitative estimates turned out to be unexpected for us.

According to accepted approaches to the interpretation of BP variability parameters, the increase in spectral power reflects an increase in the functional activity of mechanisms regulating BP [30]. The power of the LF (sBP) range is determined by the sympathetic tone, the HF (sBP) range is associated with breathing, and the VLF (sBP) range reflects the slowest effects of humoral regulation. In our study, we found an increase in the power of all ranges of the spectrum, together with a decrease in the relative power of the LF (sBP) range associated with a sympathetic tone. This implies a relative increase in the contribution of other mechanisms involved in BP and HR regulation: the minor role of the increase of sympathetic influences on the cardiovascular system can also explain the decrease in HR that was revealed in 2020.

According to modern views based on neuroimaging data, suprabulbar effects on BP are determined by the so-called sympathetic connectome, a morpho-functional formation in the brain [31] consisting of the insula, hypothalamus, and some areas of the limbic system. Modern methods of brain research extended the list of systems involved in BP regulation, which confirmed at the level of functional architecture long-known empirical data on the sensitivity of BP to stressful situations (through the limbic structures) [3,7] and to the state of humoral regulatory systems originating from the hypothalamus.[6,14,15,17] These influences on the cardiovascular system usually modulate the spectral power of the VLF range in the HR spectrum.[25] Changes in the power of this range were demonstrated in the study of HR variability during Stroop testing and during recovery after it.[32] It was found that when the test is performed as a variant of psychological stress, the power of the VLF (HR) range decreased, while the LF/HF ratio, on the contrary, increased, which is considered a correlate of increased sympathetic influences. During the recovery period, the LF/HF ratio returned to baseline in less than 15 min, while the power of the VLF (HR) range did not return to the initial level even after two hours.

In our study, we observed a tendency to a decrease in the power of the VLF (HR) range in adolescents during the period from 2004 to 2020, which can be interpreted as the presence of more pronounced psycho-emotional tension in adolescents in 2020 in comparison with 2004. This result can be determined by the fact that we conducted measurements directly at school, and during classes, while measurements on weekends and in medical institutions might not detect this effect.

In the BP variability spectra, we also found a decrease in the power of the VLF range, but only for dBP, which is considered a "stable component" of the arterial sphygmogram [33].

We hypothesize that the increase in psycho-emotional tension can be due to the wide introduction of computer and digital technologies into the educational environment in 2020 in comparison with that in 2004. Then, the observed shifts can be regarded as an adaptive response of the body to changes in the environment. However, our results pose a number of questions that require further studies. First, if the elevated BP and its increased spectral variability parameters are related to the educational environment, they should be reversible and compensated by the beginning of the next school day; monitoring of parameters during the school day (week, year) is necessary.

Otherwise, if the digitalization of the educational process leads to persistent hypertension in students, it is necessary to determine the limits of the safety of this technology for the health of children and to develop reasonable standards which pose a new urgent task for hygienists.

Secondly, it is necessary to study whether high reactivity for the cardiovascular system in adolescents is a risk factor of hypertension in adult life.

Of particular interest is the evaluation of possible shifts in the parameters of the cardiovascular system under conditions of distant learning, e.g. under restrictions during the COVID-19 pandemic, when the time spent by students in a digital environment not for the purpose of entertainment significantly increased.

It is important to remember that the changes in the functional state of the BP regulation systems observed in our study, not only depend on psycho-emotional stress, but can also produce a negative impact on the health of schoolchildren in general, thus closing a "vicious circle". It is known that hypertension is perceived at the subjective level as feeling bad and negative mood that reduces the quality of social life of adolescents [34]. Objective studies have shown that adolescents with high BP demonstrated lower effectiveness in cognitive tests [35]. They also more often have emotional disorders, for example, mood disorders were observed in 37% of examinees [36]. In the case of pulmonary hypertension, the frequency of anxiety and depression exceeds 50% [37]. In general, hypertensive patients are more likely to commit hate crimes [38].

5. Conclusions

Comparative analysis of the parameters of the cardiovascular system in adolescents during school hours showed that sBP values in 2020 were higher than in 2004. The proportion of adolescents with elevated BP also increases. Analysis of the parameters of heart rate and BP variability reflecting the mechanisms of regulation of the cardiovascular system suggests that the identified shifts were caused by psycho-emotional stress. We associate this state with the use of digital educational technologies.

The revealed trend requires the close attention of school health professionals. It would be expedient to establish the practice of BP measurements at school and share hygienic recommendations on working with digital technologies for students and their parents, in addition to hygienic recommendations on the organization of the educational process with frequent breaks and alternation of educational activities. Digital technologies can also be of great help here, in the form of various gadgets that allow children and adolescents to control BP [39].

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