FEATURES OF NEUROVEGETATIVE AND HUMORAL REGULATION OF COGNITIVE ACTIVITY IN ADOLESCENTS WHEN USING ELECTRONIC DEVICES

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ABSTRACT

Background. *Studying the functional state of the body of adolescents when they preform cognitive activity using electronic devices is of great importance due to the introduction of information and computer technologies into the educational process. Identifying the characteristics of the reactivity of students' bodies when performing cognitive activities in a digital environment will contribute to both optimization of learning and health protection.*
The aim of the study. *To study the autonomic regulation of heart rate, electrodermal activity, cerebral circulation and the level of cortisol in saliva when adolescents performed a cognitive test on electronic devices (tablet, laptop) and on paper-based media.*
Materials and methods. *Using analysis of heart rate variability, electrodermal activity, rheoencephalography and enzyme-linked immunosorbent determination of cortisol in saliva, we examined 48 adolescents while performing a cognitive activity on electronic devices.*
Results. *When adolescents perform cognitive activity using electronic devices, we can register changes in heart rate variability, electrodermal activity and cerebral circulation. Cognitive activity in a digital environment causes an increase in sympathetic effect on the heart rate with a decrease in parasympathetic activity, an increase in the integrative indicator of galvanic skin response, in vascular tone and a decrease in the cerebral blood flow intensity. One in four adolescents experiences anticipatory stimulation of the endocrine system before taking a cognitive test. Correlation analysis revealed a large number of correlations between the studied indicators both in the initial state and during cognitive activity.*
Conclusion. *A large number of correlations, both in the initial state and during the cognitive test, between heart rate variability and cortisol concentration, cerebral circulation parameters indicate the preservation of a rigid system of neurovegetative and humoral regulation of heart rate when using electronic devices compared to paper-based media.*

Key words: *adolescents, cognitive load, heart rate variability, electrodermal activity, cerebral circulation, cortisol*

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ОСОБЕННОСТИ НЕЙРОВЕГЕТАТИВНОЙ И ГУМОРАЛЬНОЙ РЕГУЛЯЦИИ КОГНИТИВНОЙ ДЕЯТЕЛЬНОСТИ У ПОДРОСТКОВ ПРИ ИСПОЛЬЗОВАНИИ ЭЛЕКТРОННЫХ УСТРОЙСТВ

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РЕЗЮМЕ

Актуальность. *Изучение функционального состояния организма подростков при когнитивной деятельности с использованием электронных устройств приобретает большое значение из-за внедрения в образовательный процесс информационно-компьютерных технологий. Выявление особенностей реактивности организма обучающихся при выполнении когнитивной деятельности в цифровой среде будет способствовать как оптимизации обучения, так и здоровьесбережению.*
Цель исследования. *Изучить вегетативную регуляцию сердечного ритма, электродермальную активность, мозговое кровообращение и уровень кортизола в слюне при выполнении подростками когнитивного теста на электронных устройствах (планшет, ноутбук) и бумажном носителе.*
Материалы и методы. *Методами анализа вариабельности сердечного ритма, электродермальной активности, реоэнцефалографии и иммуно-ферментного определения кортизола в слюне обследовано 48 подростков при выполнении когнитивной нагрузки на электронных устройствах.*
Результаты. *При выполнении подростками когнитивной нагрузки на электронных устройствах происходит изменение показателей вариабельности сердечного ритма, электродермальной активности и мозгового кровообращения. Когнитивная деятельность в цифровой среде вызывает рост симпатических влияний на сердечный ритм при снижении парасимпатической активности, увеличение интегративного показателя кожно-гальванической реакции, повышение тонуса сосудов и снижение интенсивности мозгового кровотока. Каждый четвёртый подросток испытывает упреждающее возбуждение эндокринной системы перед выполнением когнитивного теста. Корреляционный анализ выявил большое количество корреляционных связей между изучаемыми показателями как в исходном состоянии, так и в ходе когнитивной деятельности.*
Заключение. *Большое количество корреляционных связей как в исходном состоянии, так и при выполнении когнитивного теста между показателями вариабельности сердечного ритма и концентрацией кортизола, параметрами мозгового кровообращения свидетельствует о сохранении жёсткой системы нейровегетативной и гуморальной регуляции сердечного ритма при использовании электронных устройств по сравнению с бумажным носителем.*

Ключевые слова: *подростки, когнитивная нагрузка, вариабельность сердечного ритма, электродермальная активность, мозговое кровообращение, кортизол*

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INTRODUCTION

At the moment (in 2019–2024), the Russian Ministry of Education is implementing a federal project «Digital Educational Environment» aimed at creating a digital educational environment, under which digital services and content for educational activities are being developed and introduced, which implies the active use of electronic devices (ED) in the education of children and adolescents. No doubt, the use of electronic devices in the educational process, on the one hand, will increase the interest, motivation and independence of students [1], but on the other hand, it can have a potentially negative impact on the functional state of the body: forced working posture, tension of the muscles of the neck, upper shoulder girdle, back [2, 3], heavy load on vision [4, 5], increased intensity of mental activity, fatigue [6]; i.e., the use of electronic learning tools for the body of schoolchildren will be physiologically challenging. There is a known fact that mental load causes changes in the activity of the nervous autonomic and endocrine systems [7, 8]. There is practically no information about neurovegetative and humoral regulation of cognitive activity in adolescents when working by means of electronic devices.

THE AIM OF THE STUDY

To study autonomic regulation of heart rate, electrodermal activity, cerebral blood flow and cortisol levels in saliva when adolescents perform a cognitive test using electronic devices (tablet, laptop) and paper-based media.

MATERIALS AND METHODS

The study was conducted in 2022 at one general educational organisation in Moscow; 48 students (26 boys, 22 girls) of 7th grades (13–14 years old; average age 13.83 ± 0.11 years) took part in it. The study was conducted in the first half of the day (from 9.00 to 14.00), at the time of the greatest activity of physiological functions. Exclusion criteria were acute infectious disease or exacerbation of chronic disease. Prior to the survey, the parents of the participants gave written informed consent for their children to participate in the study.

In order to assess heart rate variability (HRV), electrocardiogram (ECG) was recorded using a computer cardiograph «Poly-Spectr-8/E» (Neurosoft, Ivanovo). ECG was recorded in the sitting position, before cognitive task presentation (baseline) and at the 1st–5th, 6th–10th and 11th–15th minutes of test performance (load). Cardiointervalograms were studied by methods of HRV temporal and spectral analysis to assess the state of the autonomic nervous system.

To assess HRV, we used temporal indices (normal-to-normal RR intervals (RRNN), ms; standard deviation of NN intervals (SDNN), ms; root mean square of successive RR interval differences (RMSSD), ms; proportion of NN intervals differing by more than 50 ms (pNN50), %) and spectral (total power (TP), ms^2; high frequency (HF), low frequency (LF) and very low frequency (VLF) oscillations, ms^2) analyses. The LF/HF ratio was used to assess the balance of the autonomic nervous system (ANS) (the ratio of sympathetic and parasympathetic influences) [9]. Heart rate variability was assessed at 3 stages of test performance (1–5 min, 6–10 min, and 11–15 min of test performance).

The galvanic skin response (GSR) was assessed using the Dianel-5120 hardware and software system (Nelian CIT LLC, Moscow), recording the electrocutaneous conductance on the terminal phalanges of the 4th and 5th fingers of the right and left hands at baseline and for 15 min during the cognitive task on electronic devices and paper-based media. Galvanic skin response is an objective indicator of the level of activity of the sympathetic section of the autonomic nervous system.

Cerebral blood flow was studied by rheoencephalography (REG) in bifrontal (F-F) leads using the device «Rheo-Spectrum» (Neurosoft, Ivanovo). The cerebral blood flow was assessed by the following indices: a/T (%) – the ratio of the period duration of the ascending part of the wave (s) to the duration of the whole rheowave (T, s); di (%) – dicrotic index; AFR (c.u.) – amplitude-frequency ratio, which reflects blood flow per unit time.

The response of the endocrine system of the trainees to a cognitive task performed using various electronic devices and paper-based media was assessed by the concentration of cortisol in unstimulated saliva, which was collected in plastic disposable tubes before and after the test. Saliva samples were stored in a freezer at -20 °C until analysis. Optical density and hormone concentration values were determined using a reagent kit from DRG (USA) in StatFax 2100 enzyme immunoassay analyser (Awareness Technology, USA) and expressed in ng/mL. All analyses were performed according to the protocol of the kits, controls were within accepted limits.

During the study, students performed the Anfimov table test using different electronic devices: HP RTL8723BE laptop (HP Inc., USA) (15.6 inch screen, 1366 × 768 pixels resolution, LED backlighting with LED technology) and iPad 3 tablet (Apple Inc., USA) (9.8 inch screen, 2048 × 1536 pixels resolution at 264 ppi, LED backlighting with IPS technology).

"The Anfimov's tables" test is a task that assesses mental performance and is used to assess the stability, distribution and switching of attention in children and adolescents. The test consisted of the following: on the screen of an electronic device, the test subject was presented with a letter table, looking through it from left to right, it was necessary to find the letter highlighted in colour at the beginning of the line, marking with the help of certain keyboard keys or pressing the touch screen with a finger. The time to complete the task was 15 minutes. The control was the performance of "the Anfimov's tables" test on paper-based media, in which the subjects consistently found a letter and crossed it out with a pencil/pen. The letters to be marked during the test were given at the beginning of each line.

All adolescents completed a 15-minute "the Anfimov's tables" cognitive task on ED (tablet, laptop) and paper-based media (one trial per day). ECG, REG and GSR were recorded before (baseline) and during the 15-minute task. Saliva was collected before and after testing.

Statistical processing of the obtained data was performed using SPSS 26 computer programme package (IBM Corp., USA). Since the vast majority of the studied indicators did not have normal distribution, we used methods of nonparametric statistics with calculation of median (Me), lower (Q1) and upper (Q3) quartiles. Pairwise comparison of paired samples was performed using the Wilcoxon test, for comparison of independent samples the Kraskell-Wallis test and the Mann-Whitney test were used. The closeness of statistical relationship between the indicators was assessed using correlation analysis (Spearman's coefficient). Differences were considered statistically significant at $p < 0.05$.

The study of adolescents was performed in accordance with the decision of the Bioethics Committee of the Institute of Age Physiology of the Russian Academy of Education (Minutes No. 1 dated February 17, 2023).

RESULTS

Statistical analysis revealed no differences in the studied indicators of both the response of the autonomic nervous and endocrine systems, cerebral blood flow at baseline, and the response to cognitive load (the Anfimov's proofreading test) performed by boys and girls on a laptop and tablet, so the results of the studies were combined into one group – electronic devices, and were not separated by «gender».

The results of our study showed that the intensity of mental performance (N), i.e., the total number of characters viewed when performing the test on electronic devices and paper-based media, was not statistically significantly different ($p = 0.652$) (Fig. 1). However, the total number of letters crossed out (M) and correctly selected (S) was 1.5 times greater on paper-based media than on ED ($p = 0.0001$) (Fig. 2).

When analysing the calculated indicators of mental performance, it was revealed that the value of such indicators as attention concentration (K, %), mental productivity coefficient (E, characters) and mental performance (Au, characters/s) were 1.7–2.0 times higher when working on paper-based media than on ED ($p = 0.0001$) (Fig. 3). Meanwhile, no statistically significant differences were found between ED and paper-based media in a number of indicators such as attention stability (Ku, c.u.), volume and speed of visual information processing (V and Q, characters) ($p = 0.565$-0.652).

Therefore, despite the fact that the intensity of mental performance when working on ED and paper-based media was almost the same, the qualitative indicators were higher on paper as a more familiar medium.

It should be noted that the most pronounced changes in time and frequency indices of heart rate variability were observed from the 11[th] to the 15[th] minute of work with Anfimov's tables regardless of the medium.

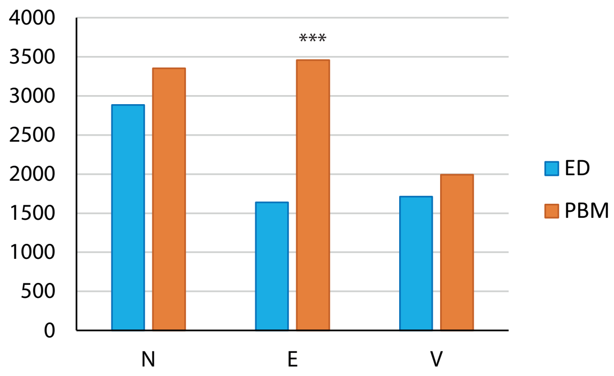

FIG. 1.
Indicators of mental performance presented as median: PBM - paper-based media; N - total number of letters viewed (characters); E - mental productivity coefficient (characters); V - volume of visual information processing

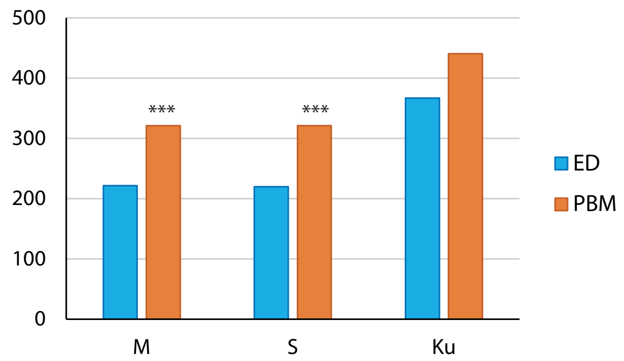

FIG. 2.
Indicators of mental performance presented as median: PBM - paper-based media; M - number of crossed out letters (characters); S - number of correctly selected letters (characters); Ku - stability of attention concentration (c.u.)

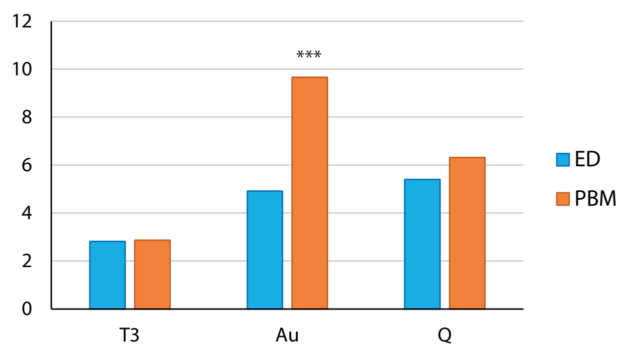

FIG. 3.
Indicators of mental performance presented as median: PBM – paper-based media; T3 – accuracy (c.u.); Au – mental performance (characters/s); Q – speed of visual information processing (characters)

Performance of the cognitive task on electronic devices in 7th grade students resulted in statistically significant decrease in total heart rate variability (decrease in TR, RRNN, SDNN values), a pronounced decrease in the activity of the parasympathetic part of the ANS (decrease in HF nu, HF% values) and a shift in the activity of the autonomic nervous system towards increased sympathetic influences (increase in LF nu, LF% and LF/HF values). HRV fluctuations in the range of VLF-spectrum reflecting neurohumoral and metabolic level of regulation did not change statistically significantly (Table 1).

During the cognitive paper-based media test in adolescents, there was an increase in low-frequency oscillations and increased sympathetic activity at the 11th–15th minute of the test (increased LF nu, LF% and LF/HF values).

GSR is used as an objective marker to assess sympathetic activation of the ANS during cognitive load. During ED work (Fig. 4a), statistically significant dynamics of changes in the amplitude (AM, μA) and integrative index of GSR activity (CA, cNp/min) of the left arm at the 11th–15th minute of cognitive load compared to baseline were revealed ($p = 0.023$ and $p = 0.015$, respectively). During paper-based media work (Fig. 46), there was a statistically significant increase only in the integrative index of GSR activity (CA, sNp/min) of the left hand ($p = 0.017$); the amplitude value (AM, μA) at baseline and after cognitive load did not change statistically significantly ($p = 0.087$).

The results of the study of cerebral blood flow when performing the cognitive task using ED and paper-based media (Table 2) revealed that all adolescents, regardless of the type of medium, showed an increase in vascular tone in the frontal leads (A_art., Ohm) and a decrease in cerebral blood flow intensity in the frontal leads (ACF, c.u.).

The study of the functional state of the adrenal cortex in adolescents in the whole group by the level of cortisol in saliva has revealed that the performance of the cognitive task using ED and paper-based media was not accompanied by a statistically significant change in cortisol concentration ($p = 0.537$ and $p = 0.311$, respectively).

TABLE 1

DYNAMICS OF HEART RATE VARIABILITY INDICES WHEN PERFORMING A COGNITIVE TEST ON ELECTRONIC DEVICES AND PAPER-BASED MEDIA

Indices	Electronic devices, Me (Q1; Q3)			Paper-based media, Me (Q1; Q3)		
	initial state	11-15 min.	*p* value	initial state	11-15 min.	*p* value
HR, bpm	85.40 (80.00–96.30)	91.80 (85.15–100.65)	**0.001**	82.10 (80.30–94.55)	95.00 (86.95–98.55)	**0.001**
TP, ms^2	3174.0 (1708.5–3922.0)	2201.0 (1492.0–3256.5)	**0.010**	2590.0 (1862.5–3861.5)	1832.0 (1305.0–3064.5	0.294
VLF, ms^2	981.0 (469.5–1465.0)	812.0 (553.5–1079.5)	0.100	963.0 (586.5–1490.5)	739.0 (470.5–1332.5)	0.064
HF, ms^2	640.0 (421.5–1116.5)	343.0 (202.0–591.0)	**0.000**	642.0 (166.5–1050.0)	276.0 (166.0–425.0)	0.133
LF, ms^2	995.0 (577.0–1487.0)	841.0 (599.0–1435.5)	0.406	1005.0 (644.0–1242.0)	791.0 (579.5–1428.0)	0.753
HF nu	40.6 (26.90–50.70)	29.0 (16.75–41.05)	**0.000**	36.40 (25.40–49.90)	29.2 (20.05–33.00)	**0.009**
LF nu	59.4 (49.30–73.10)	71.0 (58.95–83.25)	**0.000**	63.6 (50.10–74.60)	70.8 (67.00–79.95)	**0.009**
LF/HF, c. u.	1.46 (0.97–2.72)	2.44 (1.43–4.96)	**0.000**	1.75 (1.02–2.94)	2.43 (2.04–4.08)	**0.033**
VLF%	33.8 (26.50–42.55)	37.4 (31.15–43.55)	0.532	42.2 (33.40–49.55)	39.5 (31.60–44.15)	0.421
HF%	27.5 (16.35–31.95)	16.6 (9.85–23.55)	**0.001**	22.7 (13.20–31.80)	18.1 (11.30–21.20)	0.196
LF%	37.9 (29.90–45.45)	45.6 (34.30–51.05)	**0.030**	36.1 (27.80–42.20)	43.1 (36.40–50.25)	**0.039**
SDNN, ms	57.0 (42.5–64.0)	45.0 (40.0–55.5)	**0.008**	50.0 (43.50–64.50)	43.0 (37.00–54.50)	0.135
RMSSD, ms	40.0 (27.0–49.5)	30.0 (21.0–40.0)	**0.002**	37.0 (23.50–52.00)	25.0 (20.50–35.50)	0.126
pNN50, %	15.7 (4.30–30.8)	6.10 (2.20–17.75)	**0.003**	37.0 (23.50–52.00)	5.00 (1.85–11.50)	**0.001**
CV, c. u.	8.00 (6.65–9.10)	7.26 (5.87–8.56)	0.056	7.30 (6.31–8.39)	6.49 (5.93–8.36)	0.507

Note. *p* – statistically significant differences between baseline and load.

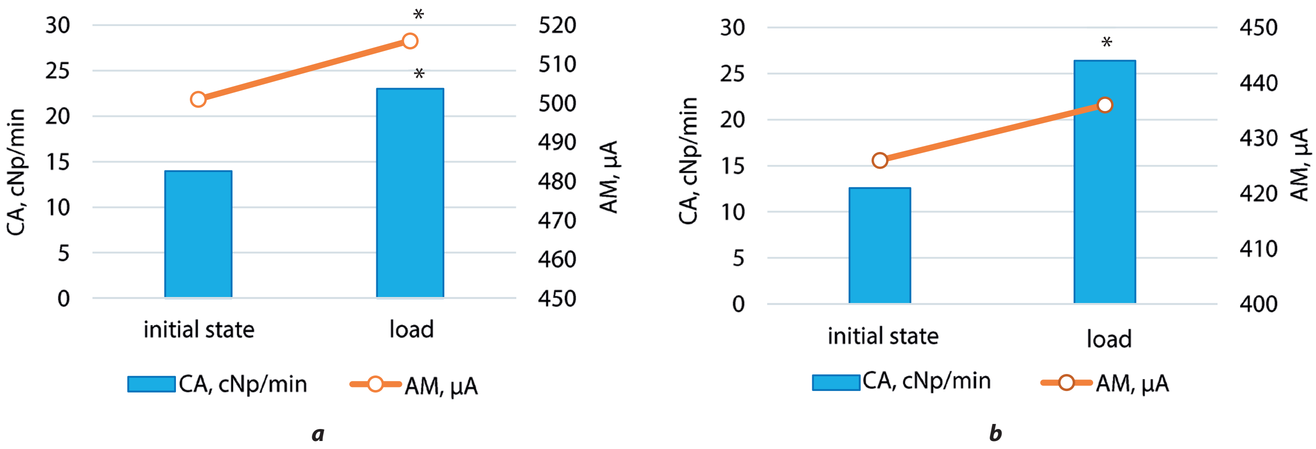

FIG. 4.
*Indices of cutaneous galvanic response at baseline and while performing cognitive load using electronic devices (a) and paper-based media (b): * – differences are statistically significant at p < 0.05 compared to the baseline state*

At the same time, individual analyses of cortisol dynamics allowed to reveal two types of response: Type I (60 % of adolescents) – increase in the level of the hormone (by 11 % when performing the ED load, 17 % – when performing on paper-based media); Type II (40 % of adolescents) – decrease in the level of cortisol (by 17 % when performing the ED load, 10 % – when performing on paper-based media) (Fig. 5).

Figures 6–8 represent the data of correlation analysis of heart rate variability, cerebral blood flow, cortisol level and mental performance during the cognitive task performed on ED and paper-based media. Before working on electronic devices, a greater number of correlations between heart rate variability indices, on the one hand, and cerebral blood flow indices and cortisol level, on the other hand, compared to the initial state before working on paper-based media (Fig. 6). The most significant correlations were observed between the total power spectrum (TP, ms^2) and its components (HF, LF, VLF, ms^2) with cerebral blood flow (AFR, c.u.) (r = -0.392-0.410; $p < 0.05$) and small calibre vascular tone (di, %) (r = 0.419-0.703; p < 0.05-0.01).

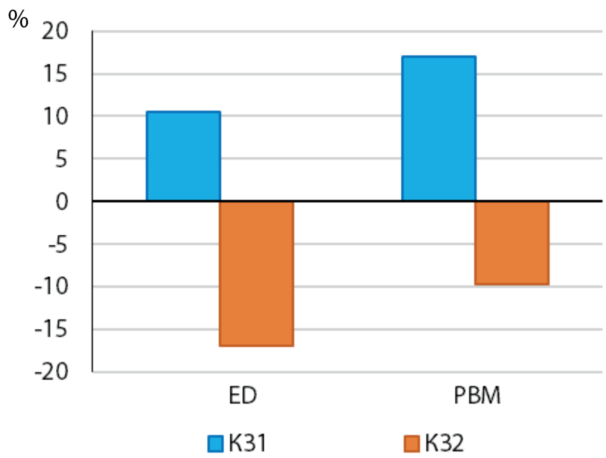

FIG. 5.
Dynamics of cortisol concentration increase depending on the type of reaction to the cognitive task performed on electronic devices and paper: PBM – paper-based media; K31 – I type of reaction; K32 – II type of reaction to the cognitive task

TABLE 2

DYNAMICS OF CEREBRAL BLOOD FLOW INDICES DURING COGNITIVE TASK PERFORMANCE USING ELECTRONIC DEVICES AND PAPER-BASED MEDIA

Indices	Electronic devices, Me (Q1; Q3)			Paper-based media, Me (Q1; Q3)		
	initial state	11-15 min.	*p* value	initial state	11-15 min.	*p* value
A_art, Ohm (FF_1)	0.18 (0.15–0.22)	0.13 (0.11–0.17)	**0.000**	0.15 (0.13–0.19)	0.10 (0.09–0.12)	**0.023**
AFR, c.u. (FF_1)	2.63 (2.10–2.95)	2.10 (1.82–2.43)	**0.000**	2.38 (1.90–2.61)	1.65 (1.39–1.92)	**0.002**

Note. *p* – statistically significant difference between baseline and load.

The ED test also reveals a higher number of connections compared to the paper-based media test (Fig. 7). The most significant relationships were observed between measures of heart rate variability and large vessel tone (a/RR) (r = -0.449-0.491; $p < 0.01$). Almost all correlations of cortisol levels with HRV indicators disappear, leaving only a negative association with HF spectrum waves (r = -0.37; $p < 0.05$). There were no statistically significant correlations between cortisol levels and the above indices both at baseline and during the paper-based media task.

During the cognitive ED task, cortisol levels were found to correlate with such indices of mental performance as the number of correctly selected letters (S), mental productivity coefficient (E), attention concentration (R), visual information processing speed (Q), and mental performance (Au) (r = 0.36-0.37; $p < 0.05$). During cognitive task on paper-based media, close correlations (r = 0.63-0.66; $p < 0.05$) were revealed between the same indices of mental performance and the integrative index of GSR activity (CA of the left hand, cNp/min) reflecting sympathetic activation of the autonomic nervous system.

DISCUSSION

The changes that we observe in the modern education of children and adolescents: the introduction of electronic devices (computers, laptops, tablets, etc.) into the educational environment – change the nature of learning activities and entail the need for physiological assessment of the optimisation of learning of the younger generation. In this regard, we conducted a study of autonomic regulation of heart rate, electrodermal activity, cerebral blood flow and cortisol levels in saliva when adolescents perform a cognitive test (Anfimov's tables) on electronic devices (tablet, laptop) and paper-based media.

According to the data of the research conducted by the Institute of Age Physiology of the Russian Academy of Education in 2019 and 2022, the duration of continuous computer use during a lesson in 7th grades (13.8 min) and the cumulative time of electronic media use per day during lessons (38 min) do not exceed the normative values allowed by the «Sanitary and Epidemiological Requirements for Organisations of Upbringing and Education, Recreation and Health Improvement of Children and Youth» [10]. Consequently, in this study, the 15-minute duration of adolescents' performance on the cognitive test did not exceed the acceptable values.

The results of the study revealed that mental performance (total number of letters crossed out and correctly selected, attention concentration, mental productivity coefficient, and mental efficiency) was 1.5–2.0 times higher when working on paper-based media than on ED. It is known from the literature that school-aged children and adolescents are better at solving maths problems, reading and performing tests on paper-based media than on electronic devices [11-14], i.e. most researchers agree that the traditional medium is the first choice for information perception and processing. The greater number of errors made by adolescents when working on the ED may be the result of the different viewing angle from which the subject looks at the vertical laptop screen and/or the horizontally placed task form on the desktop [15].

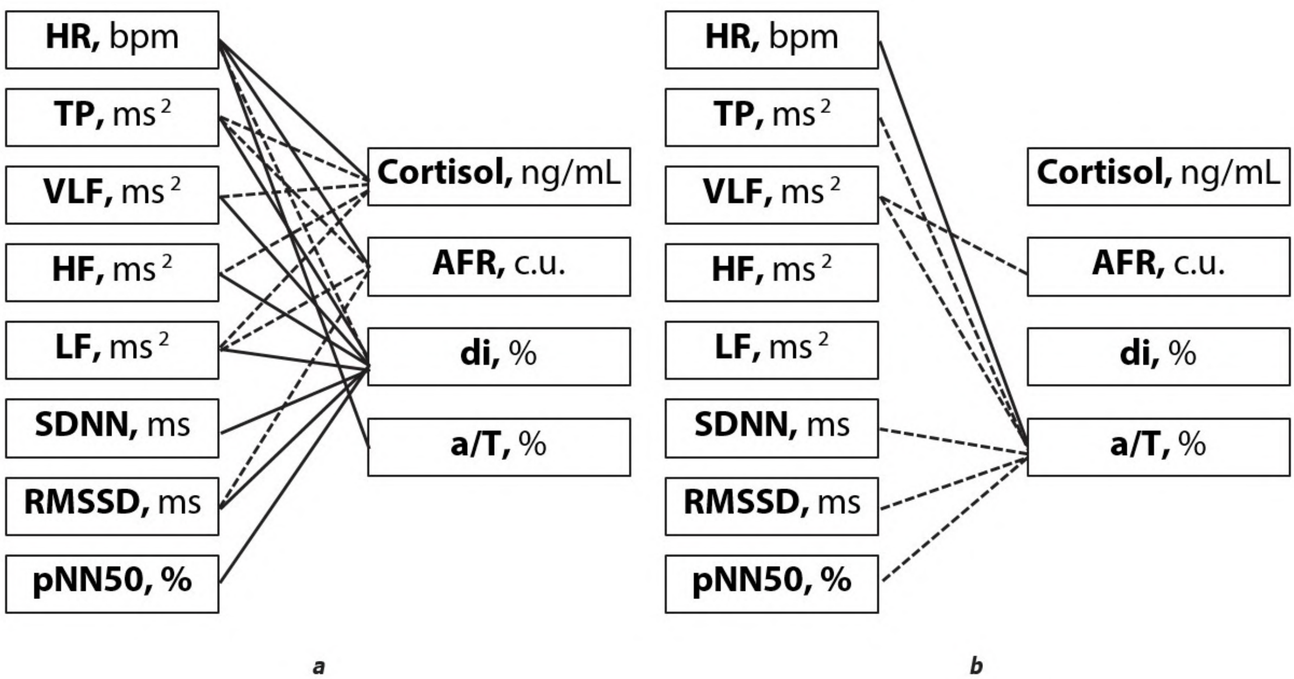

FIG. 6.

Correlations of heart rate variability, cerebral blood flow and cortisol level before cognitive task performance using electronic devices (a) and paper-based media (b) (p < 0.05): solid line – direct relationship; dotted line – inverse relationship

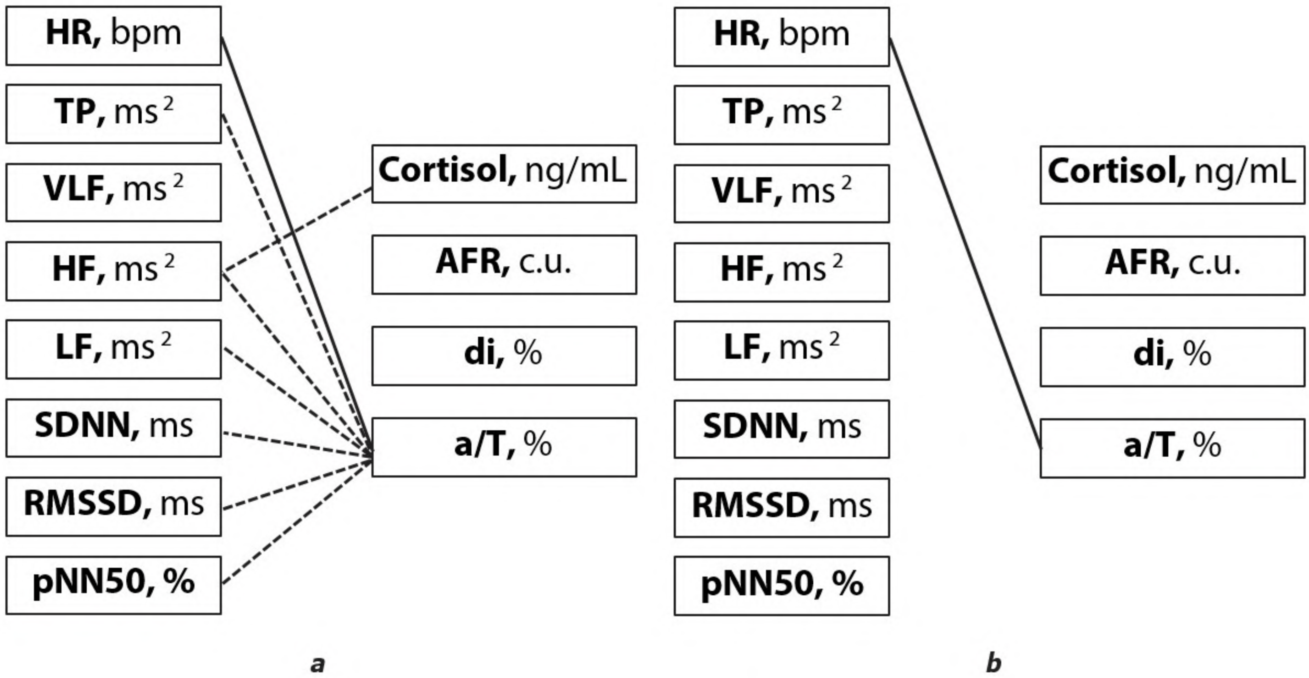

FIG. 7.
Correlations of heart rate variability, cerebral blood flow and cortisol levels during cognitive task performance using electronic devices (a) and paper-based media (b) (p < 0.05): solid line – direct relationship; dotted line – inverse relationship

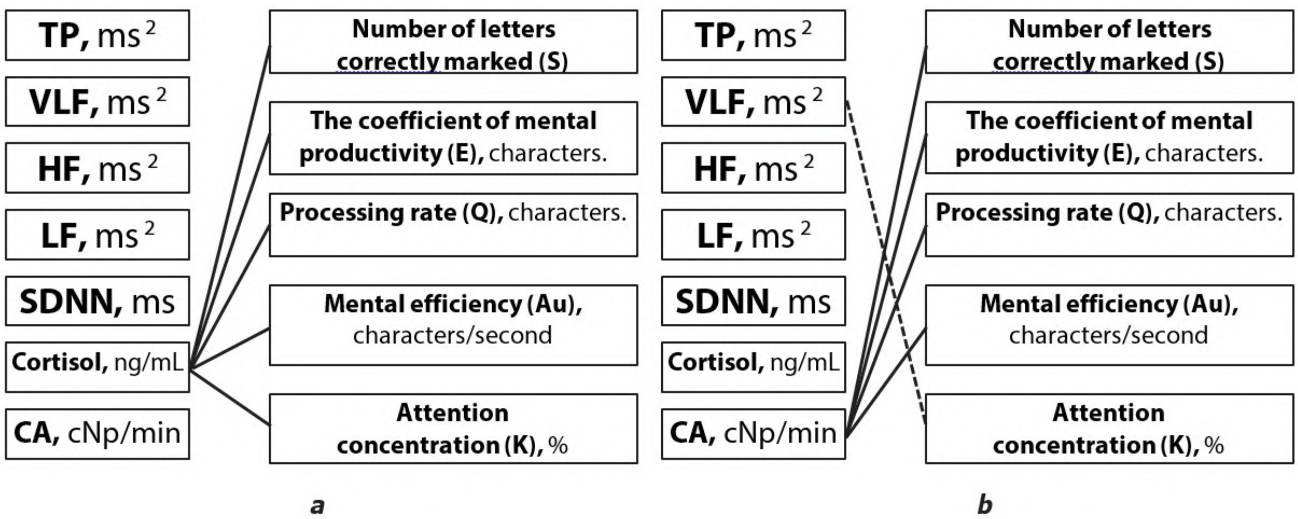

FIG. 8.
Correlations of heart rate variability, cerebral blood flow and cortisol levels during cognitive task performance using electronic devices (a) and paper-based media (b) (p < 0.05): solid line – direct relationship; dotted line – inverse relationship

Additionally, performing tasks on a computer increases the load on the systems that are involved in information processing [16], which can also affect mental performance.

Performance of a cognitive task using electronic devices in 7th grade students caused a decrease in total heart rate variability and parasympathetic activity, and an increase in sympathetic influence of the ANS. In the study by L. Mygind et al. (2018) [17] also observed a decrease in vagus nerve tone in children 10–12 years old when performing a task similar to the Anfimov's Tables test. Presumably, a rapid decrease in parasympathetic activity in response to environmental factors leads to efficient mobilisation of energy and prompt return to the resting state [18], indicating «parasympathetic flexibility» [19].

Individual analyses revealed two types of endocrine response to cognitive load: increased or decreased cortisol levels. In this study, one in four adolescents had a higher cortisol concentration at baseline than after cognitive load. At this case, one speaks of anticipatory arousal of the endocrine system [20], which is manifested by increased cortisol levels in adult individuals before an exam [21], in children before entering school [22], which may be associated with insufficient regulatory capacity [23]. It is likely that cognitive activities in the digital environment were more stressful for some adolescents than traditional paper-based media testing, so their endocrine system was already activated before the cognitive load.

Correlation analysis revealed a large number of correlations between heart rate variability parameters with cerebral blood flow parameters, cortisol levels before working on electronic devices. According to P.K. Anokhin's theory of functional systems, coordinated interaction of individual physiological systems occurs to achieve a useful adaptive result. In other words, adaptive potential is provided by a complex of changes in several physiological systems of the organism [24].

The presence of statistically significant correlations between the total power of the spectrum and its components with cerebral blood flow (AFR) and small calibre vessel tone (di) at baseline indicates the need to maintain normal blood supply of nervous tissue, in which there is a decrease in tonic tension of cerebral arteries of small calibre, without involvement of large vessels, which is a manifestation of cerebral blood flow autoregulation [25]. The existence of correlations between the indices of the autonomic nervous system and cortisol level indicates a more generalised reaction involving not only autonomic but also humoral regulation in the situation of waiting before performing a test on electronic devices.

Changes in the number and direction of interrelations between various organismal parameters characterise the course of adaptation processes better than the absolute values of these parameters. The number of connections between the studied parameters during cognitive activity decreased, but the number of connections is greater when performing the test on ED compared to paper-based media. The most significant relationships are observed between heart rate variability indices and tone of large vessels (a/T, %). The increased oxygen demand of the brain is mainly satisfied by the increase in blood flow, which is associated with a decrease in the tone of large vessels [26]. The negative correlation between cortisol level and ANS parasympathetic activity during work with ED may indicate the mobilisation of adolescents' body reserves during adaptation to cognitive activity. This interdependence has been found in adolescents who speak publicly to unfamiliar audiences [27].

Correlations between cortisol levels and mental performance were revealed during the ED cognitive task. This is explained by the fact that cortisol in a situation of mild to moderate stress has a beneficial effect over the organism [28], increases the mobility of nervous processes, enhances brain work efficiency [29], i.e. a moderate and short-term increase in the level of cortisol contributes to the improvement of cognitive functions, in our case – an increase in mental performance. When performing a cognitive test on paper-based media, a positive relationship between the same indicators of mental performance and sympathetic activation of the ANS (according to GSR) was revealed, indicating that cognitive functions are provided by sympathetic regulation [30].

CONCLUSION

The conducted study allowed to reveal that mental efficiency, assessed by such indicators as the total number of crossed out and correctly selected letters, concentration of attention, mental productivity coefficient, mental efficiency is 1.5–2.0 times higher when working on paper-based media than on ED, i.e. cognitive activity is more productive when performing the test on a familiar paper-based media. When working on electronic devices, there is a significant decrease in parasympathetic (as measured by HRV) and increase in sympathetic activity (as measured by HRV and GSR); when working on paper-based media, these physiological changes are less pronounced. During cognitive activity, regardless of the type of medium, there is a decrease in arterial blood flow and an increase in vascular tone in the frontal lead. The presence of a greater number of correlations both at baseline and when performing the cognitive test between HRV indices, on the one hand, and cortisol concentration and cerebral circulation indices, on the other hand, indicates the preservation of a rigid system of neurovegetative and humoral regulation of heart rhythm when using electronic devices compared to paper-based media. This may indicate a strain on the adaptation of the organism of 13-14 year old students during cognitive activities in the digital environment.

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Conflict of interest
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