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Original Research Article

Changes in the dynamics of latent periods of simple sensorimotor responses throughout the academic year in Moscow schoolchildren over 10 years

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The purpose of our investigation was an assessment of changes in the dynamics of the proportions of latent periods of simple sensorimotor responses to stimuli of different modalities throughout the academic year in Moscow schoolchildren over 10 years. We analyzed latent periods of simple sensorimotor reaction to light and acoustic stimuli in first-and fifth-grade schoolchildren using equipment "computer movements meter ". The proportion of the latent periods of the sensorimotor reaction to stimuli of different modalities was studied in dynamics from the beginning to the end of the school year and in comparison with similar results obtained 10 years ago. Evaluation of statistical significance performed in both time periods using algorithms for the dependent variables (nonparametric Wilcoxon paired test). The frequency of occurrence of different variants was assessed using Fisher exact test. It was found that in first grade children, the latent periods of the reaction to stimuli of different modalities were equal in approximately 50% cases. In one-third cases, the latent periods of the response to acoustic stimulus were longer than to visual stimulus; in modern first graders, unlike their peers 10 years ago, this parameter decreases over the academic year. Similar annual dynamics, even more pronounced, was observed in fifth graders in observations performed 10 years ago. It is concluded that the observed changes reflect shifts in the functional state of child organism (and probably, cognitive capacities) under the effect of new environmental factors, including educational factors. The findings are important in the management of the education system and in the planning of innovations in educational technologies.

Key words*:* psychomotor integration, sensorimotor reactivity, acoustic stimuli, visual stimuli

INTRODUCTION

The time of sensorimotor reactions (simple or complex of varying degree of complexity) is a widely used parameter in studies evaluating the functional state of human body (Shutova, Murav'yova, 2013); along with the time of task performance, informative parameters are accuracy (with or without errors – missed or interstimulus reactions) and latent period of the reaction.

In neurophysiological tests, the total time of test performance is considered as a result of integrative activity of the brain (Bernstein, 1967). In psychological experiments aimed at studying the cognitive processes, the total reaction time is usually analyzed (Gusev et al., 2014; Klasik et al., 2006). In neurophysiological experiments, the interval between perception of the sensory stimulus and beginning of the motor reaction, i.e. reaction latency, is important (Samuel, Sengupta, 2005). By the present time, the age-related dynamics of functional maturation of the sensory and motor systems of human brain and age-related

Table 1. Sample characteristics (age, gender, and anthropometrics)

	2003-2004			2013-2014		
	boys	**girls**	**total**	**boys**	**girls**	**total**
	1st graders					
n	45	40	85	41	48	89
Age, years (M±SE)	7.27±0.11	7.23±0.09	7.25±0.07	7.16±0.03	7.11±0.05	7.15±0.03
Body length, cm (M±SE)	128.5±1.2	125.5±1.4	127.0±0.9	123.6±0.7	121.2±1.2	123.1±0.6
Body mass, kg (M±SE)	28.7±0.7	26.9±1.2	27.8±0.7	26.1±0.7	25.4±0.9	25.9±0.6
	5th graders					
n	19	19	38	14	13	27
Age, years (M±SE)	11.43±0.09	11.14±0.09	11.25±0.07	11.27±0.09	11.22±0.14	11.23±0.08
Body length, cm (M±SE)	147.7±1.7	146.9±1.2	148.8±1.0	147.5±1.6	145.2±1.8	146.6±1.2
Body mass, kg (M±SE)	42.2±2.1	40.7±1.5	41.1±1.2	44.1±2.7	36.4±1.5	43.1±1.9

dynamics of the main parameters of the sensorimotor integration are well studied (Arceneaux et al., 1997). Therefore, evaluation of the latencies of simple sensorimotor reactions is highly important for the diagnosis of functional brain development in children (Dionne-Dostie et al., 2015), especially in the context of early (prenosological) detection of possible dysfunctions that can lead to communication disturbances (Le Bel, 2009), speech disorders (Nelson et al., 2006), or school problems (Willcutt et al., 2010). Moreover, disorders in the sensorimotor integration have a negative impact on the formation of specific goal-directed behavior (Machado et al., 2010), which not only hampers school learning, but also affects the whole life. Since it is known that the time of nerve impulse conduction in humans attains definitive values by the age of 6 years (Udupa Chen, 2013), we can assume that the latent period of simple sensorimotor reaction starting from this age is mainly determined by the capacities of the sensorimotor integration.

It has been shown that speed and accuracy characteristics of the sensorimotor reaction are not constant, but are modulated by external influences on the central nervous system; noteworthy, the speed and accuracy of sensorimotor reactivity parameters depend on attention stability (Shutova, Murav'yova, 2013). Clinical studies have demonstrated that children with logopaedic problems also have problems with voluntary attention to auditory and visual stimuli, which is determined, among other things by the time of the sensorimotor reaction. Tests with auditory and speech stimuli, but not visual stimuli, are most difficult for these children (Ebert, Kohnert, 2011). Speech disorders, including dyslexia, are often associated with physiological and psychophysiological problems in perception of the auditory information (Rosen, 1999). Autism, a disorder that becomes more and more prevalent in recent years (for a number of reasons) is characterized by impairment of basic processes of perception of information, including sensory information (Marco et al., 2012). Evaluation of the parameters of sensorimotor response to nonverbal stimuli is used in differential diagnosis of various cognitive disorders (Armstrong et al., 2001), in particular, disturbances accompanying attention deficit with hyperactivity disorder (Tamm et al., 2012), that becomes more and more prevalent in many countries (Reinhardt , Reinhardt, 2013). In the latter case, differences in the reaction latency to auditory and visual stimuli are important (Tinius, 2003).

Hence, the relationship between the parameters of the sensorimotor reactivity to stimuli of different modalities (one of these is acoustic stimulus) can be used as an indicator of functional state of child organism. Objective characteristic of physiological capacities of the organism, including its adaptation to changing socio-psychological and natural environmental factors, has become an important problem in recent years due to active introduction of computer and media technology into the educational process.

The objective of this study was to evaluate the proportion between the latent periods of simple sensorimotor reaction to light and acoustic stimuli in first and fifth graders in dynamics from the beginning to the end of the academic year and in comparison with similar results 10 years ago.

MATERIALS AND METHODS

Examinees and design of the experiment

Testing was performed in two Moscow schools (Russia). In 2003-2004, first and fifth graders of school No. 1357 were examined (85 and 38 children, respectively). In 2013-2014, we examined first and fifth graders of school No. 1008 (89 and 27 children, respectively). General description of the subjects is presented in Table 1. We found no statistically significant differences by the gender, age, body weight and height between the samples examined in 2003-2004 and 2013-2014.

The tests were performed in late September–early October and then in late April (start and end of the academic year, respectively), always before noon. All tests were performed in accordance with Articles 5, 6 and 7 of Universal Declaration on Bioethics and Human Rights after

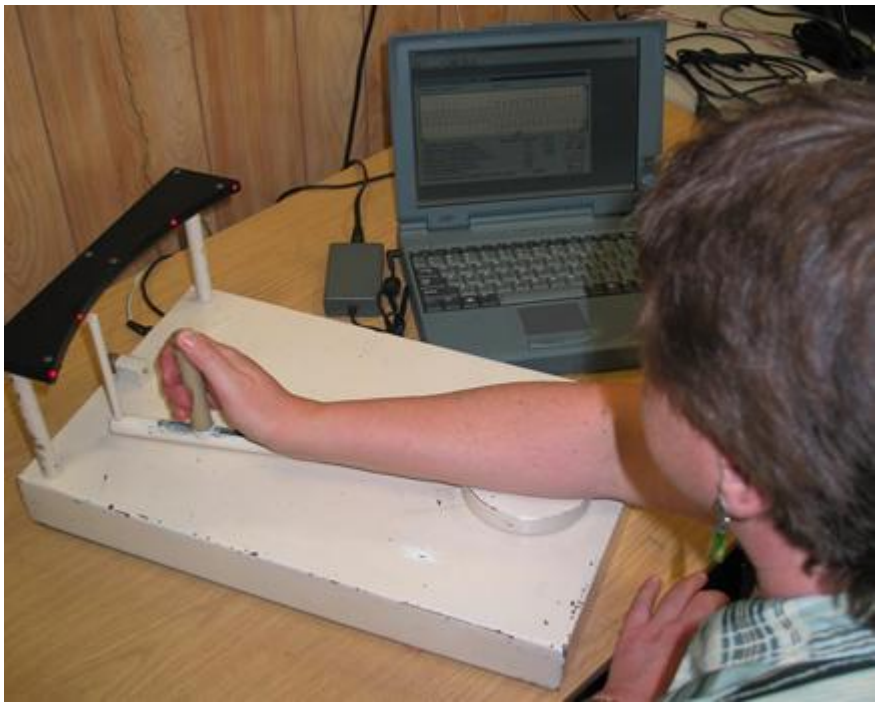

Figure 1: Hand position during CMM testing

written consent was obtained from children and their parents (or legal representatives).

Equipment

Latent periods of the simple sensorimotor reaction to light and acoustic stimuli (RTV: reaction time to visual stimulus, RTA: reaction time to acoustic stimulus) were measured using CMM hardware-computer complex (CMM: computer movement meter, "INTOX" St. Petersburg, Russia). In this complex, RTV and RTA are measured as follows: the examinee should respond to the presented stimulus by rapid lever pushing by the hand (forearm) followed by its return to the initial position (Figure 1).

The test is performed with hands changing, 10 presentation of each modality for each hand, 0.4 sec stimulus duration; the interval between the stimuli randomly varied from 2 to 4 sec. The test duration for each hand and each stimulus modality was 30 sec. The latent period of the reaction to each stimulus was measured and the mean value was calculated from 10 presentations. This algorithm meets common requirements for the evaluation of the latent periods of simple sensorimotor reaction (Hummel et al., 2006; Parekh et al., 2004).

In our study, we attempted to reveal changes in the proportion of sensorimotor reactivity to stimuli of different modality related to changes in the functional state of the examinees under the effect of environmental factors. However, changes in the functional state also manifest in shifts (sometimes even inversion) of lateralization in various psychophysiological parameters (Fokin, 2007). The efficiency of test performance by the ipsi- and contralateral hands (relative to the dominant hemisphere) considerably differs (Iacoboni et al., 1998). Therefore, in our study, the results of the tests performed by the left and right hands were averaged (only one parameter was used for each modality - mean time of task performance by both hands). It was accepted that the latent periods differ if RTA differ from RTV (RTA>RTV, RTA<RTV) by more than 15%; otherwise RTA=RTV. These criteria have been developed in our laboratory and tested over more than 10 years (Polysystemic approach, 2013).

Statistical processing of the results

The data were processed statistically by nonparametric Mann-Whitney test for independent variables, Wilcoxon paired test, and Fisher exact test (Statistica 7.0 software). Nonparametric tests were used because the distribution of latent periods of simple sensorimotor reaction to stimuli of different modalities did not conform the normal distribution (Kolmogorov-Smirnov test).

RESULTS

No statistically significant changes in the average values of the latent periods of simple sensorimotor reaction to different stimuli for 10 years were revealed (Table 2). The only difference between today's students from their peers 10 years ago there were no changes for the school year dynamics in averaged values of sensorimotor reactions

Table 2. Latent periods (M±SE, sec) of simple sensorimotor reaction in samples of both time periods. Significance of differences (evaluated by Wilcoxon's test) from the results of autumn testing: # – $p < 0.05$

	2003-2004		2013-2014	
	autumn	spring	autumn	spring
	1st graders			
n	85	85	89	89
Light stimuli	0.294±0.006	0.264±0.005 #	0.289±0.006	0.270±0.007
Acoustic stimuli	0.318±0.007	0.282±0.007 #	0.308±0.008	0.288±0.008
	5th graders			
n	38	38	27	27
Light stimuli	0.206±0.005	0.196±0.004	0.206±0.009	0.186±0.006
Acoustic stimuli	0.217±0.006	0.204±0.006	0.213±0.009	0.196±0.008

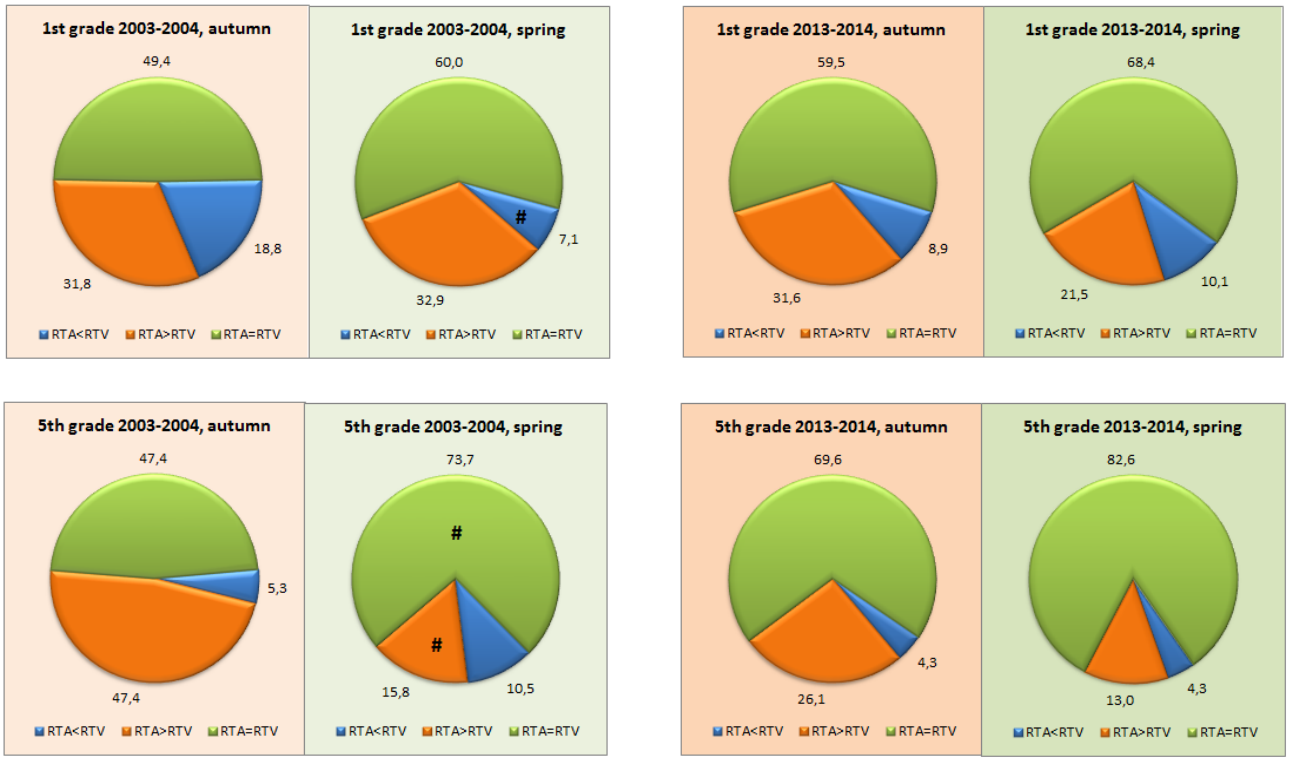

Figure 2: Proportions of first graders (upper panel) and fifth graders (lower panel) with different ratios of the responses to light and acoustic stimulation. On the figure: RTV: time (latency) of the reaction to light stimulus; RTV: time (latency) of the reaction to acoustic stimulus. Statistical significance of differences (Fisher exact test – two-tail χ^2 test) from the results of autumn testing. # – $p < 0.05$

latent periods in first graders, but not in the fifth graders.

In our study, in both time periods RTV was lower than RTA in a small part of first and fifth graders (Figure 1), while in most cases, the latencies of these reactions were close (RTV=RTA). Ten years ago, RTA surpassed RTV in a greater part of first graders (but the differences were statistically insignificant: χ^2=3.37, p=0.075; Figure 2, upper panel). For detection of the potential influence of educational environment factors on the functional parameters of child body, of particular interest are the cases with longer latency of the sensorimotor reaction to auditory stimulus in comparison with that to visual stimulation RTV>RTA. Ten years ago, these children constitute ~32-33% of the examined first graders and this parameter did not change throughout the academic year (Figure 2, upper panel), while the proportion of cases with RTV<RTA significantly decreased (χ^2=5.22, p=0.037). Now, the percentage of RTV<RTA cases tended to decrease (χ^2=2.38, p=0.149). According to averaged data, RTA in first graders surpassed RTV by 8-10% and this difference changed throughout the academic year nether in this survey nor 10 years ago (Figure 3). Averaged data also revealed no shifts in proportion of children retaining the RTV to RTA ratio or demonstrating more than 15% shortening of whatever latent period (Figure 4).

Ten years ago, RTV in an almost half of fifth graders

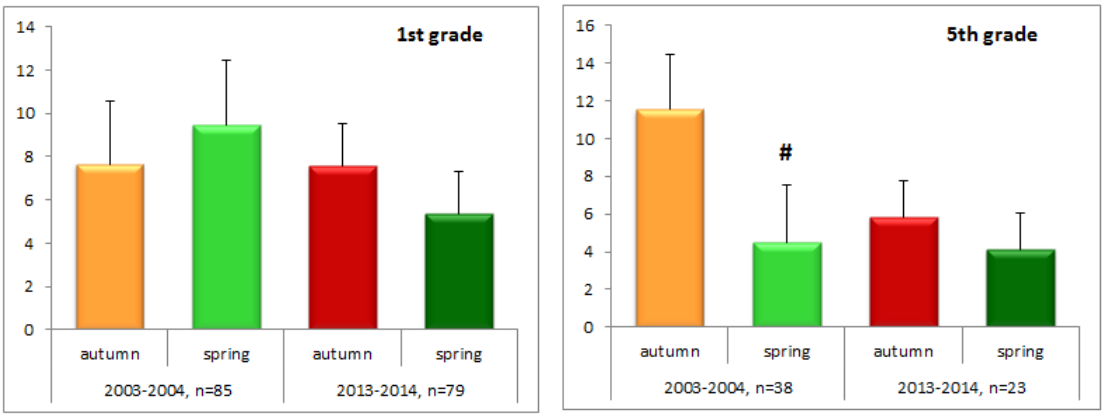

Figure 3: Surplus (%) of the reaction time to acoustic stimulus over time response to light stimulus in first graders (left panel) and fifth graders (right panel). Significance of differences (evaluated by Wilcoxon's test) from the results of autumn testing: # – $p < 0.05$.

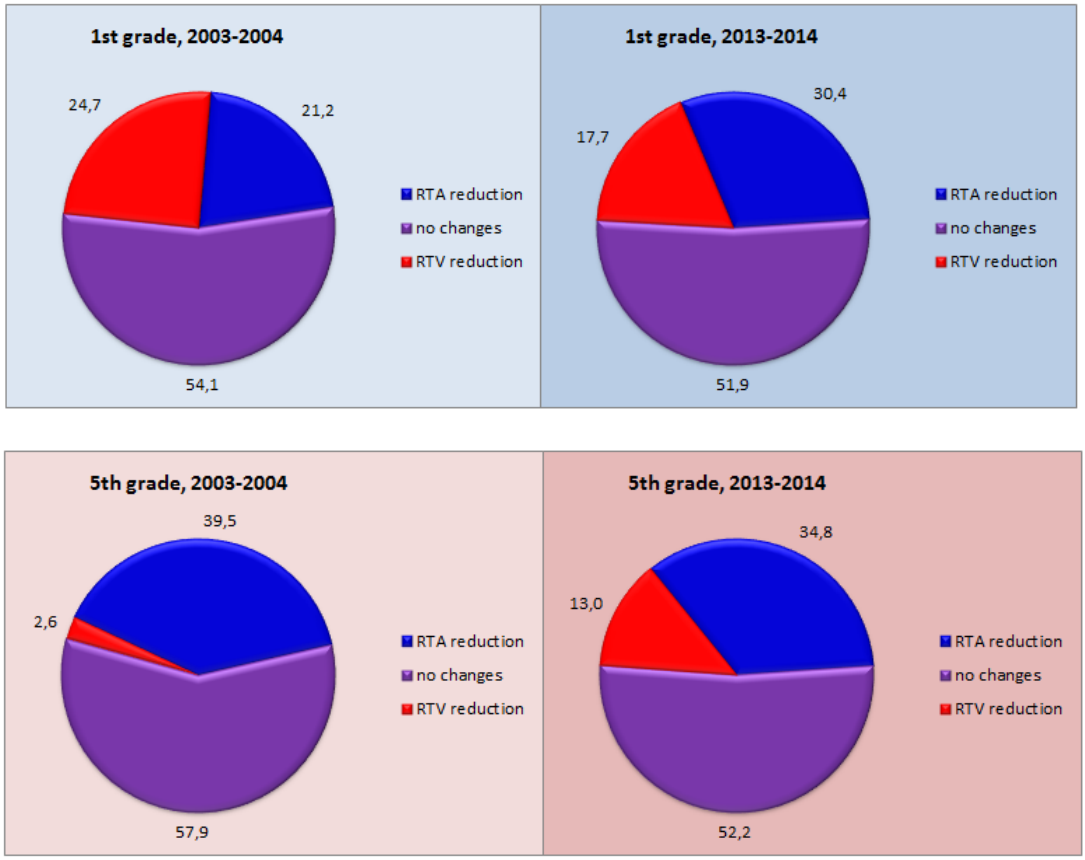

Figure 4: Proportions of first graders (upper panel) and fifth graders (lower panel) with different dynamics of response latency to stimulation of different modality throughout the academic year.

surpassed RTA, but the proportion of these children significantly decreased by the end of the academic year (χ^2 =8.77, p = 0.006; Figure 2, lower panel). According to averaged data, the excess of RTV over RTA significantly (Z= .081, p =0.036) decreased (Figure 3). These findings probably reflect initially stressful (with subsequent adaptation) effect of transition from the primary to middle school (in Russian schools this corresponds to the fifth grade), in particular, transition to the system of specialized classrooms, more teachers, and new requirements. At present, the effect of adaptation (decrease in the percent of children with RTV>RTA) is retained only at the level of a

trend (χ^2 =2.47, p=0.161), probably because of a tendency towards a decrease in the percent of children with RTV>RTA during the initial (autumn) testing in comparison with the results obtained 10 years ago (Figure 2, lower panel). Hence, changes in the averaged surplus of RTA over RTV during the school year did not attain statistical significance (Figure 3).

DISCUSSION

According to neurophysiological data, the latencies of simple sensorimotor response to auditory (but not speech) stimuli should be slightly shorter than the latency of the sensorimotor response to visual stimuli (Roth, Sack, 1990; Iacoboni et al., 1998; Rauschecker, 2011). The absolute duration of the reaction depends on the two major components. First, genetically determined characteristics of the nervous system simultaneously manifested in the parameters of the electrical activity of the brain (Korobeynikova, 2000) and cognitive capacities. The latter are evaluated in schoolchildren by fixation of active attention (Gribanov, Kanzhina, 2008), academic achievement (Korobeynikova, 2000; Vergunov, 2009), ot IQ (Korobeynikova, 2000; Park et al., 2011). These properties of the nervous system can develop differently under different environmental conditions (including, educational environment). We assume that this group of factors can determine the differences between today's schoolchildren and their peers 10 years ago. The influence of environmental factors, first of all social factors, e.g. lifestyle, is proven for various cognitive disorders, including attention deficit with hyperactivity disorder (Klassen et al., 2004) and autism (Martinez-Sanchis, 2015). It is important that the effects of environmental factors are not related to cultural traditions of the society (Willcutt, 2012), but are determined by previous experience of children and adolescents (Quatman-Yates et al., 2012). It is proven that purposeful training can induce plastic rearrangements in the central nervous system changing the terms of functional maturation of the sensorimotor integration systems (Flor, Diers, 2009). The results obtained in our laboratory also suggest that the age-related dynamics of functional maturation of physiological parameters in schoolchildren can be modified by various educational technologies (Polysystemic approach ..., 2013). That is why cognitive disorders of childhood have attracted much attention of not only researchers, but also experts of public health institutions (Thapar et al., 2013).

Second, the latency of the sensorimotor response depends on the functional state of the body that, in turn, is sensitive to both actual physiological status (emotional background, anxiety, exhaustion, hunger or satiety, etc.) and experimental conditions (relaxed or stressful situation, completeness of instructions for performing the test, previous experience in solving similar tasks, noise, odors, etc.) (Shutova, Murav'yova, 2013). To minimize the effects of the latter, the tests were performed under the same conditions. Hence, the differences in the dynamics of the latent periods of the sensorimotor responses to stimuli of different modality over the academic year are most likely determined by different dynamics of the functional state of the child organism.

The above findings drove us to a conclusion that the observed dynamics of the studied parameters primarily reflects the effects of factors of educational environment, including, first of all, recent changes in the methodology of educational activities implying widespread introduction of computer and media technologies and second, reorganization of the Russian Educational system and implementation of new principles of education that is not confined to knowledge transfer, but is also aimed at the formation of practical skills. The emphasis is laid on the ability of data search in different virtual libraries, which substantially increases the time of Internet surfing. Naturally, specifics of the operating new high-speed computers and various devices surely affects reactivity of immature nervous system of the child to various external stimuli.

Conclusion

Evaluation of the proportion between latent periods of simple sensorimotor responses to auditory and visual stimuli is a sensitive tool for assessment of the functional state of the body in children and its changes under the influence of educational environment factors. It was found that in first grades, the latent periods of the reaction to stimuli of different modalities were equal in ~50% cases. In one-third cases, the latent periods of the response to acoustic stimulus were longer than to visual stimulus; in modern first-graders, unlike their peers 10 years ago, this parameter decreases over the academic year. Similar annual dynamics, even more pronounced, was observed in fifth graders in observations performed 10 years ago. It is hypothesized that the observed changes reflect shifts in the functional state of child organism (and probably, cognitive capacities) under the effect of new environmental factors.

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