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DYNAMICS OF MENTAL CAPACITY OF SCHOOLCHILDREN DURING STUDY IN SECONDARY SCHOOL UNDER CONDITIONS OF IMPLEMENTATION OF VARIOUS EDUCATIONAL PROGRAMS

Zhanna Sotnikova-Meleshkina, Tetiana Havrylova, Olha Zinchuk, Iryna Dudnyk

The aim: *to describe the dynamic changes in mental capacity during education in secondary school in the implementation of traditional and meritocratic educational program.*
Materials and methods. *The study involved 56 secondary schoolchildren in the dynamics of learning, which were divided into 2 groups depending on the education system. The level of mental capacity was assessed using proofreading tests of V. Ya. Anfimov. Statistical data processing was performed using one-way analysis of variance and t-test in the software package IBM SPSS Statistics 20.*
Results. *During the period of basic education, the level of influence of the type of educational program, type of subject and day of the week on the accuracy of the test performance increased, the amount of work increased by 16.2-16.7 % ($p<0.01$) and its accuracy decreased ($p<0,05$). Higher initial and post-load intensity of mental capacity was revealed in schoolchildren with meritocratic education (353.23±8.52 and 341.41±8.65 respectively), and with a traditional system - higher and stable accuracy (5.68–5.86 errors) and productivity of mental work (35.29-35.72 conventional units; $p<0.01$). The weekly efficiency curve was the opposite in terms of accuracy for 6th and 9th grade schoolchildren, and the identical in terms of volume. In meritocratic education, a higher level of intensity was registered in the mathematics lesson, and in the traditional educational program − accuracy against the background of negative dynamics of quantitative and complex indicators.*
Conclusions. *Gender and age features of intensity, accuracy and productivity of mental work during basic education and the level of influence of factors of the educational process on them are established. The increase in the level of educational load was accompanied by an increase in the intensity and accuracy of mental work due to the adaptation of schoolchildren to the peculiarities of learning in secondary school and the stabilization of physiological processes. Comparison of weekly curves of mental capacity during training allowed to identify certain age trends in the formation of mental fatigue*
Keywords: *schoolchildren, mental capacity, meritocratic education, secondary school, dynamic changes*

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1. Introduction

Conditions of educational activity are related to the introduction of new forms of learning and global informatization, which places increased demands on the psychophysiological capabilities of schoolchildren [1, 2], creates serious emotional, cognitive and physical problems [3, 4], reduces the efficiency and quality of work that affects the academic performance of student youth [5, 6].

Currently, new, specialized and author's programs are being introduced, which are characterized by great variability, accompanied by intensification of the educational process, increase in total study load, decrease in physical activity and deterioration of schoolchildren' daily routine structure [1, 2]. Many countries around the world are intensively developing and implementing new educational programs aimed at academically gifted and talented children, namely meritocratic education, the concept of which is the role of the intellectual elite in ensuring the prosperity of the state [7]. This educational system is designed to create favourable conditions for socio-psychological adaptation of academically gifted-children in the environment, the realization of their potential, its effective use for the development of society as a whole.

During the mental activity that accompanies the learning process, there are processes of receiving, storing and processing information that requires stress of sensory systems, attention, memory, emotional sphere and autonomic systems [8]. In turn, the level of mental capacity is the main factor that ensures the effectiveness of perception and processing of this information [9]. The study of age-specific mental capacity is necessary to reveal the mechanisms of fatigue as a basis for the correction of negative factors [10, 11].

Mental capacity is considered as a characteristic of an individual's ability to perform specific mental activ-

ities and is used in the research as a prognostic criterion for the development of fatigue [12, 13]. In Ukrainian research as the main research tool for determining the signs of mental fatigue use correction tests by V. Ya. Anfimov with subsequent analysis of the volume, accuracy and productivity of the work [2, 14]. This technique was used in the study of mental capacity schoolchildren [15, 16], students [12, 13], teachers [17].

However, there is no single method that could simultaneously provoke a mental load of a certain dose and assess the level of mental fatigue, there are no works that determine the dynamics of mental capacity during primary school, which solves major pressing problems to prevent mental fatigue and increase academic performance.

The outlined range of problems determined the relevance of this study, as well as the formation of its **aim**: to characterize the dynamic changes in mental capacity during primary school in the implementation of traditional and meritocratic educational program.

2. Materials and methods

The study involved 56 schoolchildren at the beginning (6th year of study, which coincides with the stabilization phase after the transition from primary to secondary education level) and at the end (9th year) of secondary school with the consent of parents, subject to Helsinki Declaration and the rights of bioethics, which is confirmed by the protocol No. 12 of 01.12.2020 of the Committee on Bioethics and Deontology of the State Institution "Institute of Children and Adolescents Health Care of the Academy of Medical Sciences". Depending on the education system, schoolchildren were divided into 2 groups: EG1 – aneducational groupwith a meritocratic educational program, EG2 – a group of children who received secondary education with the traditional system.

Two-minute correctional tests of V. Ya. Anfimov were used to assess the level of mental capacitywith further calculation of quantitative (volume of revised characters), qualitative (accuracy of work performed on the number of errors per 500 revised characters) and complex indicators (productivity ratio) in the cycle of studying 3 subjects: mathematics, Ukrainian language (basic subjects used in any educational projects and not integrated into other disciplines) and history (differs from mathematics in the level of difficulty, and from the Ukrainian language – the nature of the work operations in the lesson) [17–19].

One-factor analysis of variance and t-test in the IBM SPSS Statistics 20 software package were used for statistical data processing.

3. Research results

With the help of one-factor analysis of variance, the degree of influence of educational process factors on the quantitative (intensity) and qualitative (accuracy) indicators of schoolchildren' mental capacity at the beginning and end of secondary school was determined. It was found that during the acquisition of secondary education the level of influence of the type of educational program increased (from F=33.9 to F=294.8; $p<0.001$ at the beginning of the lesson and from F=42.1 to F=327.9; $p<0.001$ at the end of the lesson), type of subject (from F=1.66; $p>0.05$ to F=3.86; $p<0.001$) and day of the week (from F=2.35; $p>0.05$ to F=13 , 0; $p<0,001$ at the beginning of the lesson) on the accuracy of the test, but was not determined by the type of educational project on the level of impact on the intensity of mental work.

The indicators of mental capacity also changed. Thus, the number of traced signs increased both before (by 16.2 %) and after the lesson (by 16.7 %; $p<0.01$) and decreased the number of errors at the same baseline level by 17.7 % and 19.2 % ($p<0.05$), which indicated an increase in productivity.

Analysis of the quantitative and qualitative characteristics of mental capacity in educational teams with different types of educational programs (Table 1) revealed a higher initial and post-load intensity of mental work in schoolchildren under the introduction of meritocratic education system. With age, this difference was levelled due to a more significant increase in workload (by 109–112 characters depending on the stage of the lesson; $p<0.01$) under the traditional education system and the overall increase in labour intensity for both educational projects ($p<0.01$). However, the quality of mental work did not change significantly in EG2 and decreased significantly in EG1 ($p<0.01$). As a result, the traditional system of training determined a higher and stable accuracy of proofreading (5.68–5.86 errors per 500 traced characters against 11.56–12.49 errors in EG1), as well as the productivity of mental work (35, 29–35.72 c.u. vs. 31.61–32.59 c.u. in meritocratic education; $p<0.01$).

Analysis of the mental capacity of schoolchildren of different gender groups revealed its higher level in girls, both quantitatively and qualitatively, regardless of the phase of the lesson, while maintaining this pattern during basic education (Fig. 1, 2).

Table 1

Quantitative and qualitative characteristics of mental capacity during secondary school education, depending on the education system, M±m

Learning stage	Lesson phase	Mental capacity indicator			
		Intensity		Accuracy	
		EG1	EG2	EG1	EG2
6th year	before lesson	$353.23\pm8.52^{**\#\#}$	$291.90\pm5.43^{\#\#}$	$7.53\pm0.38^{**\#\#}$	5.56 ± 0.33
	after lesson	$341.41\pm8.65^{**\#\#}$	$284.99\pm5.66^{\#\#}$	$7.61\pm0.35^{**\#\#}$	5.71 ± 0.35
9th year	before lesson	405.84 ± 7.19	401.20 ± 3.55	$11.56\pm0.32^{**}$	5.68 ± 0.18
	after lesson	398.46 ± 7.13	397.91 ± 3.57	$12.49\pm0.36^{**}$	5.86 ± 0.18

Note: when compared with EG2 (– p <0.05; ** – p <0.01); in the dynamics of learning (# – p<0.05; ## – p<0.01)*

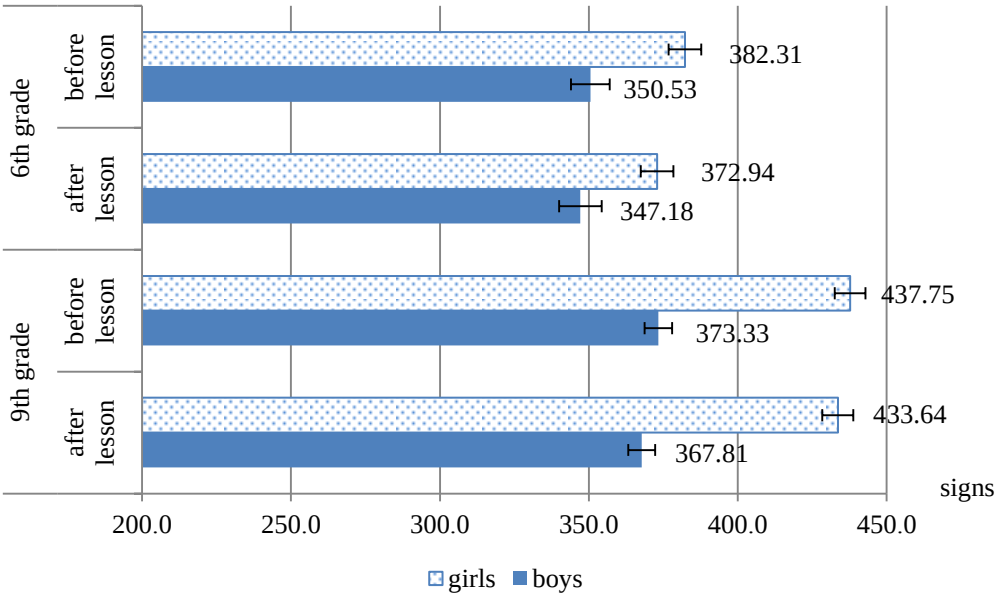

Fig. 1. Quantitative characterization of mental capacity of schoolchildren of different sexes during primary school

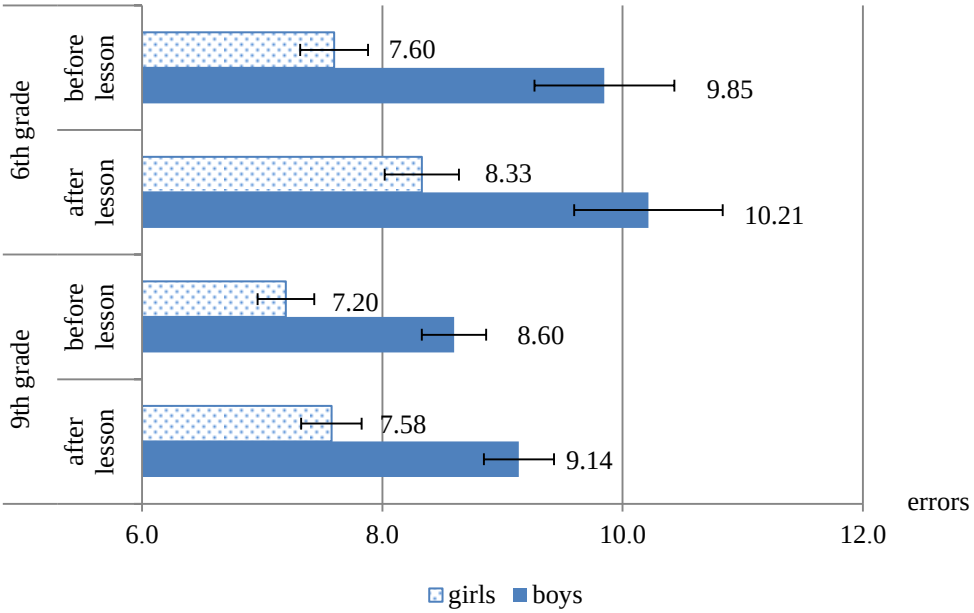

Fig. 2. Qualitative characteristics of mental capacity of schoolchildren of different sexes during primary school

Analysis of the weekly dynamics of mental capacity of schoolchildren at the beginning and end of secondary school (Fig. 3) found that starting from the middle of the week the curve of performance on a qualitative basis in sixth and ninth graders was opposite, and quantitatively – identical, with a higher-level intensity at the beginning of the week and the accuracy of mental work at the end of the week in the ninth year of study ($p<0.01$). At the same time, the maximum level of mental productivity of secondary school graduates was registered on Monday both before (CP0 – 37.65± ±0.65 c.u.) and after the lesson (CP1 – 35.40±0.66 c.u.; $p<0.05$), which was provided by the high volume of work performed against the background of the lowest accuracy. A comparison of the mental capacity curve with the class schedule showed that lower productivity was recorded on Wednesday among schoolchildren studying under the meritocratic system, and on Friday according to the traditional program.

The volume of the level of educational load in the study of different systems, respectively, on the scale of severity of subjects [19]. It was found that under the meritocratic system the level of workload in grades 5–8 is higher, and in grade 9 lower than the traditional program. At the same time, regardless of the education system, the level of workload increased from 5th to 6th grade by an average of 7.19 points (the highest in the meritocratic system), 2–3 points per year to 8th grade and decreased

slightly in the transition to 9th grade (1.30 points) mainly through training in the meritocratic system.

To determine the possible reasons for the peculiarities of mental capacity of schoolchildren in different education systems, an in-depth analysis was conducted by groups of subjects from different fields, namely: mathematics (in 9th grade – algebra), Ukrainian language and history of Ukraine (Fig. 4, 5). It was found that at the secondary school threshold under the meritocratic system (EG1) a higher level of mental capacity was registered both before and after the mathematics lesson in quantitative characteristics, and in qualitative – in the traditional educational program ($p<0.01$). During training, this pattern intensified, with the amount of work increased in both educational programs, and accuracy decreased – only in EG1.

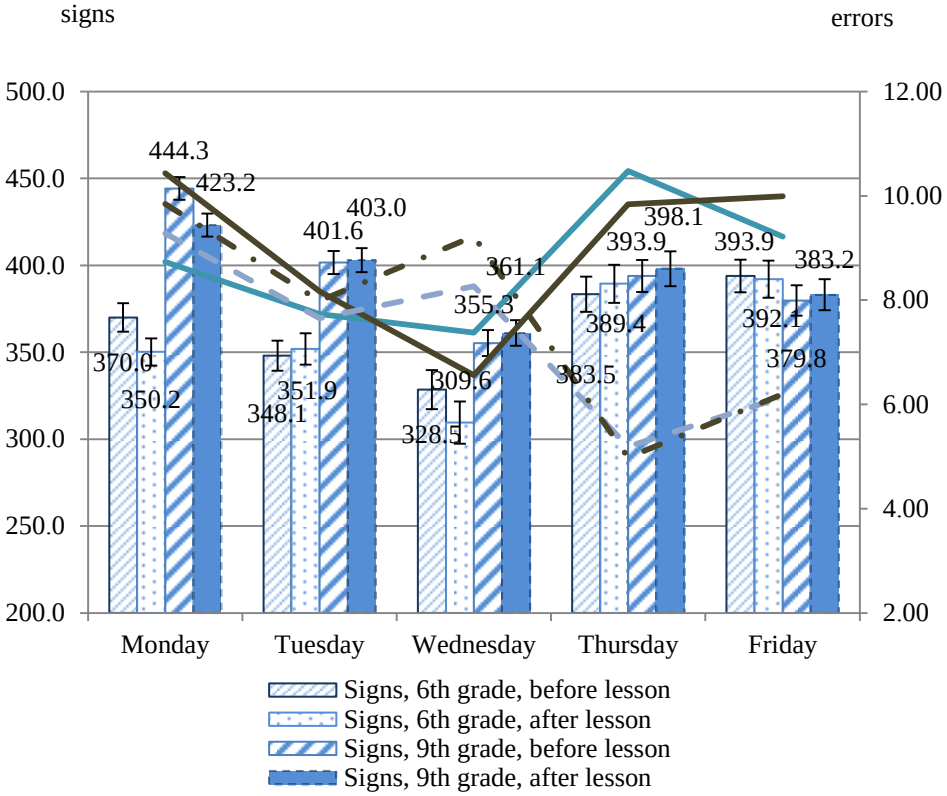

Fig. 3. Weekly dynamics of mental capacity among secondary schoolchildren

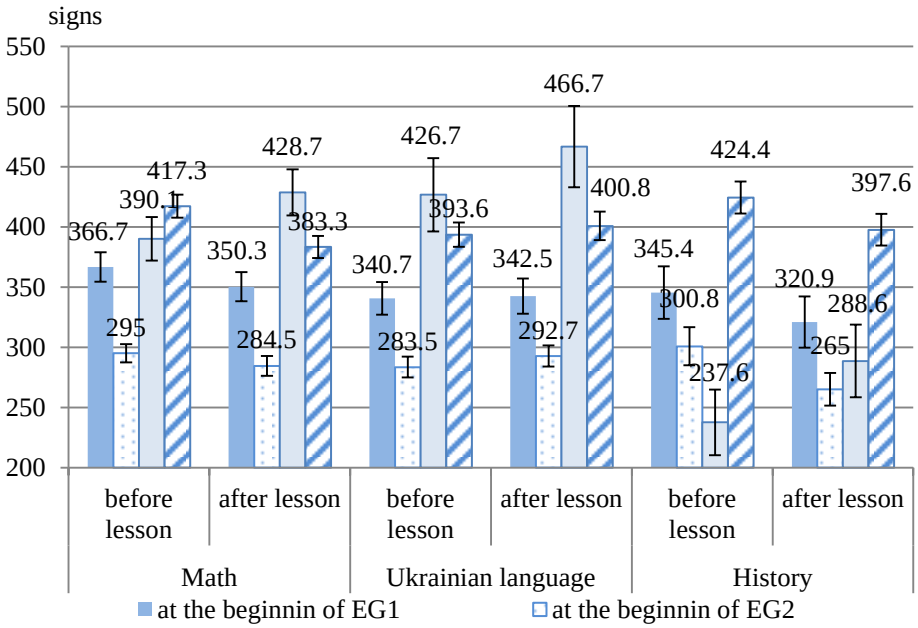

Fig. 4. Quantitative characteristics of mental capacity in the study of subjects in different directions (by the number of traced sings)

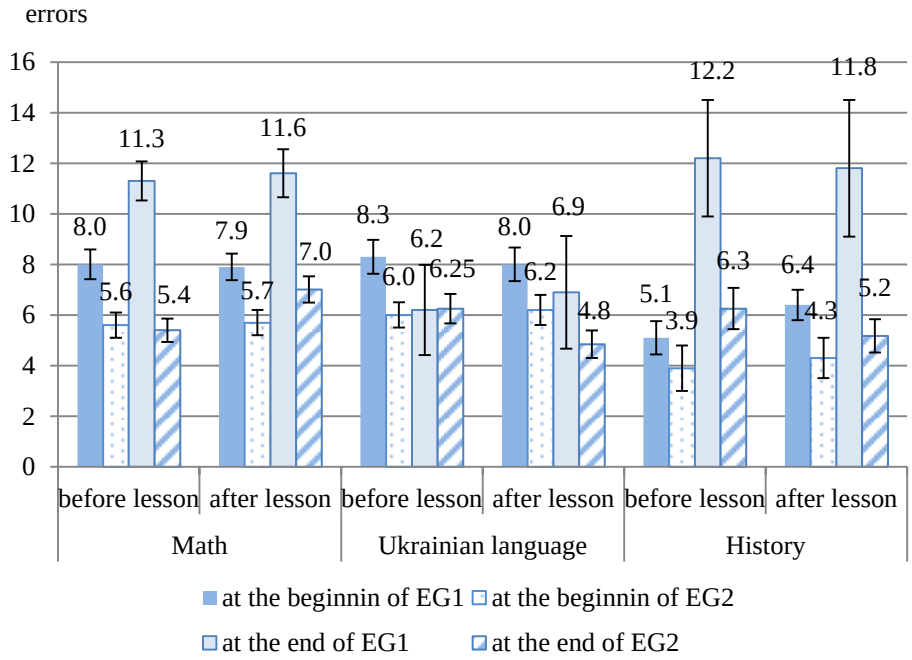

Fig. 5. Qualitative characteristics of mental capacity in the study of subjects in different fields (by the number of errors)

The study of the Ukrainian language was accompanied by dynamic changes in the intensity of mental work ($p<0.05–0.01$) without significant difference regardless of the stage of study. For EG1 schoolchildren, the history lesson was accompanied by significantly higher accuracy, a decrease in the dynamics of learning the level of mental capacity on both indicators, but their growth ($p<0.01$) and the highest accuracy (significantly compared with the Ukrainian lesson; $p<0.05$) among EG2 schoolchildren.

Generalization of dynamic changes in mental capacity depending on the complexity of the subjects found that under the conditions of implementation of the meritocratic system was characterized by a lower level of accuracy of work regardless of the severity of the subject ($p<0.01$). At the same time, students with EG1 had a higher level of quantitative indicator with a tendency to increase during primary school, as well as an increase in the complex indicator of mental capacity (coefficient of productivity) after mathematics lessons with maximum difficulty (10 points) on the appropriate rank scale. However, under the conditions of traditional education there was a negative dynamic of quantitative ($p<0.05$) and complex indicators ($p<0.01$) during lessons of the same profile.

4. Discussion of research results

One of the main problems in organizing such studies is the lack of a unified methodology that would objectively assess the level of fatigue and compare it with the level of load, which provokes a decrease in efficiency. The last decades have been marked by successes in the study of mental activity, including fatigue, efficiency and justification of physiological, psychological and hygienic measures to increase it, the normalization of mental work [1, 2].

However, the search for an integrated criterion of mental capacity remains a problem of the future for physiologists and hygienists [10, 20]. Thus, for the effectiveness of determining the level of fatigue caused by mental load, researchers recommended the use of a combination of several derivatives (subjective, behavioural and physiological) of mental fatigue [3], subjective assessment of mental load simultaneously with the assessment of working memory, electroencephalogram rhythm, skin conductivity and tympanic membrane temperature during the task [21], using signals of electrooculography, electrodermal activity and photoplethysmography [18], physiological indicators (heart rate variability, pupil diameter, flicker, eye movements with video distractor) and sub effective indicators of fatigue and mental stress [22], by measuring biometric data – electroencephalography, heart rate, heart rate variability, photoplethysmography and electrodermal activity [23]. But most research is based on tracking changes in nervous activity using electroencephalography, which is considered the gold standard for assessing mental fatigue [23, 24].

According to the research protocols, tests that cause fatigue may include experiments with short-term memory, two-hour arithmetic problems [23], tapping tests [13, 25], complex performance of 3 tasks: N-back, simulating office activities with a load on working memory (letter recognition on the screen of the device), Doctor Game (for the development of fine motor skills), Webcall (for the reproduction of the case of remote work) [18, 19], use reading several texts from web news, books and reports of the Government of Japan and collect responses to them [21], tests to assess the ability to maintain and update spatial information in working memory [26].

To assess mental load, the load index, the scale of subjective mental load, and among the criteria that characterize the level of mental capacity and fatigue are indicators of intensity and accuracy of work, the inverse efficiency and productivity index [18, 19].

Thus, for a complete and high-quality assessment of fatigue, two groups of methods should be distinguished: to provoke fatigue and ways to register its symptoms. In our study, the level of mental load that provokes the development of fatigue was assessed by analyzing the curriculum with the definition of daily and weekly dynamics based on the standard scale of severity of subjects [27, 19]. Registration of signs of mental fatigue in the training team was based on the calculation of quantitative, qualitative, and complex characteristics of mental capacity for a two-minute proofreading by V. Ya. Anfimov, which in contrast to the above methods is characterized by ease of execution, speed criteria that characterize not only the ability to work, but also its component and dynamic changes.

The study found a higher level of mental capacity among girls in all indicators, regardless of the stage of education in secondary school, which coincides with the results of previous studies [20], as well as data Zayed K., Jansen P. (2019), who found the best results tests for working memory among girls during the assessment of the organization of the educational process in lessons of mathematics, science and Arabic [28]. Gender and age features of cognitive mental processes and the effectiveness of mental work were determined in the study of high schoolchildren in different weather conditions [29]. In contrast, in a study by van Tetering M. and co-authors (2019), gender differences in three-dimensional rotation to assess mental transformation skills were determined only in the 7–12 age group with better results among boys, while in older age gender differences were not determined [30].

During dynamic observation, an increase in the intensity, accuracy and productivity of mental work was registered. In her study, Bezkopilna S. V. (2020) also identified positive mental capacity dynamics at 13–14 years of age compared to 10–11 years, but the study looked at age dynamics in people with postural disorders [9]. Changes in mental capacity were explained by certain features of physiological processes, which coincides with our conclusion on the growth of work performed as a motivational characteristic of mental work, which is associated with physiological and social maturity of ninth graders compared to 6th year schoolchildren. In our previous study on prenosological screening of autonomic regulatory stress in schoolchildren, it was found that the 6th year of study coincides with the sensitive period for autonomic regulatory systems and, accordingly, is characterized by increased sensitivity to environmental factors.At the same time, the higher "price" of adaptation to the meritocratic system of education in 6th grade compared to traditional education is determined not so much by the intensification of the educational process as by interpersonal relationships in educational teams and / or individual psychological characteristics of schoolchildren [31].

We found the highest level of mental productivity at the beginning of the week, as well as the dependence of its weekly dynamics on the distribution of workload with its decline on days with maximum workload on the scale of difficulty on Wednesday in EG1 and Friday in EG2. Changes in the mental capacity of schoolchildren during the day, week, semester, and school year in general under the influence of educational and labour activities observed by Zelenenko N. O. et al. (2017) [10].At the same time, they concluded that the duration, depth and direction of changes in the functional state of the organism, features of mental work, its conditions and organization and other reasons [10], which partly coincides with the results. Domestic researchers conducted studies of the dynamics of mental capacity, the results of which also established a high productivity of mental work in schoolchildren in the afternoon at the beginning of the school week [2].

It should be noted the peculiarities of the formation of mental fatigue and the level of mental capacity, as its criterion in the implementation of different education systems. We found that the increased level of workload characteristic of the meritocratic educational program was accompanied by lower accuracy and productivity of mental work, but also positive dynamics of mental capacity in quantitative and complex characteristics in the study of the most complex subjects of mathematics education. It is the development of schoolchildren's interest in science, mathematics, English, inventive skills is the basis of the concept of STEM education, which is positioned in meritocratic education as a leading trend of modernization of Ukrainian national education systems for continuous training in converging NBIC technologies [7]. Researchers van Tetering M. and co-authors (2019) [30] emphasized the importance of improving results in mathematical achievements and in disciplines related to STEM education.

In turn, Danish researchers have found that cognitive functions such as working and episodic memory, sustained attention and processing speed are associated with better math and reading performance [32]. The results show that sympathy for mathematics involves the choice of more complex (rather than easy) mathematical problems, as well as the strong influence of interest on both the willingness to make more effort and the feeling of less fatigue [33, 34]. In our opinion, the positive dynamics of mental capacity in terms of its intensity indicated a sufficient level of motivation during classes in specialized subjects, which coincides with the conclusions of Milyavskaya M. et al. (2021) on restoring the productivity of mental work to baseline in the presence of motivation [34–36].

Study limitations. It should be noted that physiological criteria (heart rate), as well as the emotional component (well-being, activity, mood) of mental load are assessed subjectively, which requires further search for new objective, reliable and at the same time available techniques for routine use. in large research groups.

Prospects for further researchappear in the formation of the algorithm of mental capacity analysis in combination with physiological criteria for training teams and other research groups to determine critical periods of fatigue and develop a set of measures to prevent it.

5. Conclusions

1. Gender and age features of mental capacity and the level of influence of factors of the educational process on its quantitative and qualitative indicators in 5–8 times, increase in intensity both before (by 16.2 %) and after the lesson (by 16.7 %; $p<0.01$) and decreased

the number of errors at the same baseline level by 17.7 % and 19.2 % ($p<0.05$), which indicated an increase in productivity of mental labour during basic education.

2. The increase in the level of educational load was accompanied by an increase in the intensity and accuracy of mental work due to the adaptation of schoolchildren to the peculiarities of learning in primary school and the stabilization of physiological processes.

3. Comparison of weekly mental capacity curves during training allowed to determine not only the highest level of intensity, accuracy, and productivity of mental work by increasing the productivity ratio to 37.65± ±0.65 c.u. at the beginning of the week at the final stage of basic education, but also to identify certain age trends in the formation of mental fatigue.

Conflict of interests

The authors declare there is no conflict of interest.

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Zhanna Sotnikova-Meleshkina*, Doctor of Medical Sciences, Associate Professor, Department of Hygiene and Social Medicine, V. N. Karazin Kharkiv National University, Svobody sq., 4, Kharkiv, Ukraine, 61022

Tetiana Havrylova, Assistant, Department of Hygiene and Social Medicine, V. N. Karazin Kharkiv National University, Svobody sq., 4, Kharkiv, Ukraine, 61022

Olha Zinchuk, Assistant, Department of Hygiene and Social Medicine, V. N. Karazin Kharkiv National University, Svobody sq., 4, Kharkiv, Ukraine, 61022

Iryna Dudnyk, Assistant, Department of Hygiene and Social Medicine, V. N. Karazin Kharkiv National University, Svobody sq., 4, Kharkiv, Ukraine, 61022

***Corresponding author:** Zhanna Sotnikova-Meleshkina, e-mail: zhanna.v.sotnikova@karazin.ua*