Researches on children's mathematical abilities using non-invasive brain-recording technologies

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***Abstract*— The article discusses studies using non-invasive brain recording technologies to study mathematical abilities developing in preschool and school age. Conclusions are made about the importance of the qualitative development of mathematical skills in early childhood, as well as about the possibilities of using brain-computer interfaces to train this.**

Keywords—children, education, mathematical abilities, arithmetic, numerical skills, neuroscience, EEG, fMRI

I. Introduction

Despite the rather large gap between neuroscience and education, the development of their tandem—neuroeducation—has been quite active in the last decade [1]. Researchers often resort to the use of non-invasive brain activity recording technologies, such as EEG, to study and collect neurobiological indicators in the process of various pedagogical experiments [2].

Earlier, we made a brief review [3] of articles on the use of EEG for pedagogical research. It should be noted that recently the interest of researchers in this topic has increased significantly, and in this paper, it is important to consider one aspect of such works—the development of mathematical representations in children.

This terminology is very conditional since this definition includes both the process of understanding specific mathematical concepts and operations, and the formation of certain types of thinking. For example, recently there has been an increased interest in the so-called "Computational thinking" [4]. There are works on the study of computational thinking through EEG [5, 6]. Despite the name (computational), the researchers see the primary emphasis in the development of this type of thinking in the study of IT and mathematics.

Therefore, in our review, we would like not to stay on this issue, but to pay attention to the research on the use of EEG in the field of mathematical concepts' development, especially for younger schoolchildren.

The period of study in primary school is one of the most responsible and significant periods of a person's education. At the primary school age, the knowledge base, skills, and abilities are formed. In addition, the intensive development of all cognitive processes is carried out in primary school. The child's thinking undergoes the greatest changes: from visual-effective to visual-figurative and then to verbal-logical. The study of mathematics contributes to the development of thinking to a greater extent since mathematics is the most abstract science that studies models of the surrounding world.

When studying mathematics, children get acquainted with the concept of numbers, learn operations with numbers, and how to solve tasks. This section is traditionally called arithmetic, and it is the basis for studying mathematics in primary school.

The main task of studying arithmetic in the primary school mathematics course is the formation of students' consciousness, in some cases brought to automatism and computational skills. In turn, these skills are formed as a result of mastering certain techniques and sets of calculations. Their study is based on the application of the relevant knowledge available at the time of studying a new group of calculations, acting as the theoretical basis of the material being mastered and allowing you to perform consistently a system of operations that lead to a calculated result.

To acquire "computational skills" means to know for each task what operations and in what order should be performed to find the result of an arithmetic action and perform these operations quickly enough.

In the Russian methodology of teaching mathematics to primary school students, computational techniques of M. Bantova is allocated [7]:

1) Computational techniques, the theoretical basis of which is the numbering issues.
2) Computational techniques, the theoretical basis of which is the specific meaning of arithmetic operations
3) Computational techniques, the theoretical basis of which is the properties of arithmetic operations.
4) Computational techniques, the theoretical basis of which is the relationship between the components and the result of the action.
5) Computational techniques, the theoretical basis of which is a change in the result of an action depending on a change in one of the components.
6) Computational techniques, the theoretical basis of which is a rule.

II. Research Paper Review

Separate research areas are in mathematical giftedness. The article by L. Zhang et al. [8] is devoted to the issue of mathematical giftedness in neuroscience. The cognitive prerequisites and neurocognitive characteristics of a mathematically gifted brain (event-related brain activation regions, interactions between discrete brain regions) were considered. The directions of further neurobiological research on the topic were highlighted, as well as the existing problems

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in the identification and development of mathematical giftedness.

In another study [9] the subjects were a group of 12 mathematically gifted subjects aged about 16.5 years, as well as a control group of 14 people aged about 15.4 years with an average level of mathematical knowledge. General and reasoning-specific prototypical functional connectivity patterns from all synchrostates were identified, as well as their features in the Markov chain modeling, demonstrating improved performance of synchrostate transitions in solving long-chain tasks in mathematically gifted children.

On the other side are works that explore the problems and difficulties in learning mathematics. The article by S. Cardenas et al. [10] considers the features of arithmetic processing in an addition task in children with good academic performance and children with dyscalculia. The key criterion was the ERP, in particular, the N400 and LPC components. There were noticeable differences in the academic performance of the two groups of children, as well as topographic and latent differences in LPC indicators, and there was no significant arithmetic effect of N400 in children with dyscalculia. Also, heterogeneity was found in the group of children with dyscalculia according to their working memory index.

Studies identifying difficulties in number perception are carried out using both neuroimaging techniques and standardized tests—for example, Neuropsychological test Battery for Number Processing and Calculation for a more detailed assessment of math skills [11, 12].

The paper by L. Aulet and S. Lourenco examines the features of visual perception of quantitative information and the total surface area [13]. In contrast to the view that the number is uniquely noticeable in multidimensional stimuli, evidence has been given that the area is more noticeable in the early stages of development; and less noticeable as a person grows up. This work is echoed by the study of A. Matejko and D. Ansari [14], in which attention was paid to the influence of the size of an arithmetic problem on the relationship between arithmetic and basic numerical processing. The authors point out that at the early stages of development, it is important for children to understand and learn the basic numerical concepts that precede arithmetic, including being able to build a correlation between numbers and quantities. Difficulties and successes in the ability to process symbolic and non-symbolic values can predict a child's ability to do arithmetic, so it is important to develop skills for comparing these values.

M. Libertas et al. believe [15] that the perception of numbers already at preschool age affects mathematical abilities. The quantitative indicators of the Approximate number system were measured in 200 children aged about 4 years using the non-symbolic numerical comparison task, which is a task with the selection of a larger heap of dots. Obtained values correlated with the results of the mathematical abilities test—children with the best mathematical abilities coped with the task faster and more accurately.

To demonstrate the fragility of understanding the counting process by preschool children who know the Cardinal principle C. Jacobs et al. [16] conducted a series of experiments. The experimenter used non-numeric lists to count unobservable objects in two boxes. The children had to compare the number of elements in each and choose the one that was more filled with elements and the one that was less.

The work of A. Cahoon et al. [17] is also of interest. The authors emphasize that a child's basic counting skills (mapping between number symbols and quantities, order processing, cardinal principle knowledge, and digit recognition) are developed at the preschool age. For the development of numerical skills, individual characteristics are important: working memory, vocabulary, and sustained attention, as well as socio-economic status and home numeracy environment.

It should be noted that a significant part of scientists is engaged in the study of preschoolers.

We found it interesting that the focus of research began to shift towards educational methods [18]. L. Wirebring et al. conducted an experiment in which two approaches to teaching mathematics were compared—to give students a ready-made solution to a task with multiple repetitions, or to allow them to find a solution themselves. The second group showed better results in the control testing, as well as a lower load of verbal memory.

In the course of our research, we noticed that the methods of measuring indicators of mathematical abilities are quite different. The report will consider some examples.

Conclusion

The considered topic greatly interests us, as teachers.

The timely development of mathematical skills in preschool, and even more so in primary school age, plays a significant role in the success of further education not only in mathematical sciences but also in education in general. As it was noted, the preschool period of development (3–5 years) is the basis for the formation of basic counting skills. Children who lag behind during this period face difficulties in the future. Equally important is the approximate number system, which plays an important role in the development of number mapping and arithmetic, as well as mathematical performance.

Using neurobiological research methods makes it possible to determine the interrelationships of various structures in the studied processes much more accurately. Moreover, there is a possibility to create effective systems based on brain-computer interfaces with neurofeedback for mathematical skills training [19].

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