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Using a Cognitive Simulator: Possibilities for Minimizing Self-regulatory Deficits in Cognitive Activity in Primary Schoolchildren

Olga M. Krasnoryadtseva*, Evgenia V. Eremina, Maria A. Podoinitsina, Tatiana A. Vaulina

Tomsk State University, Tomsk, Russian Federation

*Corresponding author: krasnoo@mail.ru

Abstract

Introduction. Studying the modality of sensorimotor activity of elementary school children is influenced by the demand for new research data about the developmental capabilities of cognitive simulators that are focused on strengthening self-regulatory potential of primary school students. The novelty of the study lies in the testing of the use of a cognitive simulator as a diagnostic tool that allows studying the modality of sensorimotor activity of primary schoolchildren as a psychological marker of self-regulation of cognitive activity. **Methods.** We used cognitive simulator which allows making a visual distortion in the process of solving the cognitive problem "Tower of Hanoi", which complicates the solution process. To obtain psychological and educational information for each subject (n = 6) we used the method of expert assessments. **Results.** The paper presents the results of a qualitative analysis of the video images obtained for each subject in the process of solving the "Tower of Hanoi" problem in three experimental conditions (without distortion of the visual field, with inversion of the visual field and time delay of the image). During the experimental study, we identified and described the individual indicators of invariant and variable features of sensorimotor activity of children of primary school age who have different experiences of educational achievements and self-regulation of cognitive activity. **Discussion.** We identified main characteristics of using self-regulatory resources of cognitive activity by younger schoolchildren in the process of solving a cognitive task in specially designed experimental conditions, taking into account the real educational achievements of the participants. We outline further research directions for creation of a developmental program to use this cognitive simulator to minimize existing self-regulatory deficits in cognitive activity of elementary schoolchildren as one of the significant tasks of psychological and educational support for the cognitive development of modern children and adolescents.

Keywords

sensomotor activity, elementary school children, cognitive simulator, self-regulation, cognitive activity, cognitive task

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Introduction

The growing dynamism and unpredictability of the modern world makes it extremely important to develop such skills and abilities that help person successfully navigate in new for him conditions (Kolin, 2005; 2014; Leontiev, 2020). The ongoing transformations of the life world of a modern person form new educational trends: the use of digital technologies, automation of educational processes, building new communication models between students and teachers, an increase in the number of non-standard tasks. In this regard, models of education are changing, the emphasis is shifting to new forms of presentation of material, a change in the role of the teacher, thereby starting the process of introducing new educational technologies (Galazhinskiy & Sukhanova, 2022; Drugova, Veledinskaya & Zhuravleva, 2021; Zotkin, 2012; Trubitsyna, Baranova, Bannikova & Glazkova, 2011). Students of primary general education require special attention, since younger students are very sensitive to changes, they are characterized by increased impressionability and suggestibility (Lesev & Valeeva, 2021; Barabash, 2023). This age stage is a sensitive period for the formation of learning skills and the development of cognitive processes. The processes that take place in a fundamentally new environment, implemented by a new type of activity, influence the process of personality formation. First of all, this is reflected in the cognitive processes of the student: the child's thinking, his sensation, perception and memory change (Martsinkovskaya, 2015; Zhiginas, Sukhacheva, 2015).

Recent studies show that a significant part of today's younger schoolchildren have a pronounced deficiency in the development of voluntariness and activity of attention, stable concentration (Makhnovskaya & Aristov, 2021). It is noted that the dominance of visual perception of information leads to a lag in verbal intellectual development; increasing manifestations of instability in the emotional sphere were also recorded (Gagay & Efremova, 2019). Scientists emphasize that such problems among students can lead to maladaptive behavior patterns, which will be the cause of problems in the educational process and in the social environment at the same time (Konopkin, 2011; Barabash, 2023; Preobrazhenskaya, 2019).

Many researchers who have studied the development of children have noted that primary school age is the period of a child's transition to a new level of self-awareness and knowledge of the world around him, the formation of arbitrariness in activity and the ability to control his actions (Elkonin, 2007; Mukhina, 2006; Obukhova, 1996; Brofman, Masterov & Tekoeva, 2022). This creates favorable conditions for the development of self-regulation of younger students, which is an important condition for adaptation to the educational process and serves as an indicator of the development of cognitive activity (Zinchenko, 2020; Popova, 2022).

Self-regulation of cognitive activity is a significant component of the ability and readiness for self-regulation of younger students. Children should be able to plan their actions, control their attention, be able to switch from task to task, pay attention to their emotions and manage them (Gavrilina, 2019; Kukubaeva & Sadvakasova, 2021). The work on the formation of self-regulation of younger students' cognitive activity implies not only the existence of certain rules that the child must comply with, but also the creation of special developmental conditions in the form of involving the child in cognitive activity aimed not only at developing certain cognitive skills, but also at developing operational self-control and regulation of behavior. To solve this kind of psychological and educational problems, we should pay special attention to the sensomotor activity of children of this age, which is a complex system of perception, processing and regulation of information received from the senses, which includes active interaction between body movements, perception and muscle responses (Mamina, 2020; Balanev, Tyutyunnikov & Kokh, 2022).

Sensomotor activity can be considered as an indicator of the characteristics of self-regulation, since it is directly related to the child's ability to control his body and movements (McClelland & Cameron, 2019). Research shows that self-regulation is important for child development (Puranik, Boss & Wanless, 2019), it is continuously associated with writing skills (Chandler et al., 2021), children's involvement and performance in school (Bohlmann & Downer, 2016), emotions (Gagne, Liew & Nwadinobi, 2021). Self-regulation is also studied in terms of executive functions (Vink et al., 2020), such as planning one's actions in accordance with the set goal, solving problems, paying attention to necessary stimuli, processing information received and cognitive flexibility (Rosario Rueda, Posner & Rothbart, 2005; Veraksa, Gavrilova & Lepola, 2022).

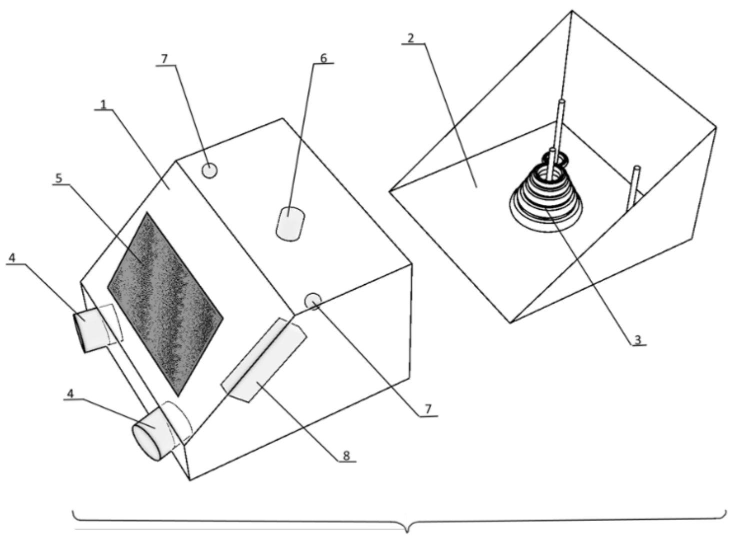
The purpose of this article is to discuss the results of a study of the modality of sensomotor activity as an indicator of the features of self-regulation of cognitive activity of younger schoolchildren using the cognitive simulator developed and previously tested on other age groups (Balanev, Smeshko & Kokh, 2022).

Methods

As a simple cognitive task, we used methodological tool that initially acted as a mathematical task, but then were introduced into the field of psychological assessment, which can be used to measure cognitive abilities – the "Tower of Hanoi" (Okulov & Lyalin, 2008). The solution of a cognitive task includes the processes of changing, supplementing, generalizing and systematizing the initial representations of knowledge using the range of their cognitive abilities (Fansher, Shah & Hélie, 2022; Šunić, 2012).

The "Tower of Hanoi" task was placed in a cognitive simulator (Balanev, Shamakov, Smeshko, Shmer & Ivanova, 2023) (Fig. 1). The test subject interacts with the simulator by placing his hands inside the body and solves the problem, performing simple mechanical actions. In the process of completing the task, the subject looks at the screen broadcasting the space in which the "Tower of Hanoi" and the hands of the subject are located. The use of the simulator allows you to make a visual distortion of the process of solving the problem, which complicates the course of the solution.

Figure 1
System for diagnostics and development of human cognitive abilities



***Note.** 1 – user interface body; 2 – stage body; 3 – a set of fasteners; 4 – two hand cuffs; 5 – device video screen; 6 – internal video camera; 7 – light source; 8 – microprocessor control device).*

All participants solved the "Tower of Hanoi" problem under three experimental conditions:

1. The condition without visual space distortion upon presentation of a normal image;
2. The condition with inversion of the visual field, i.e. the subject observed through the monitor at the subject visual scene, inverted by 180 degrees;
3. The condition with a time delay of the image.

Each experimental condition had a different degree of cognitive load on the respondent when solving the problem. The inversion of the visual field and the delay of the image, being methodological techniques in time, made it possible to “unroll” the process of perception in time. In addition to complicating the experimental conditions, the task itself became more complicated: an additional new disk was added at each stage.

The research procedure included several stages.

1. At the **first** stage, the participant was informed of the purpose of the study, then received the instruction:

"This study is aimed at studying cognitive abilities, the ability to solve cognitive problems in complex conditions and the ability to find the right strategy for solving a problem. We will be evaluating the accuracy and the speed of solving a problem in conditions of visual field reconstruction. You have the task "Tower of Hanoi". When solving a problem, you must follow certain rules:

- Do not place a larger disc on top of a smaller one.
- Do not hold the discs in your hand or place them on a table, i.e. the discs must always be placed on the stem.
- You cannot swap multiple discs at once".

Your task is to solve the "Tower of Hanoi" by making the least number of mistakes and moves.

2. On the first day of study the **second stage** for all the participants was the same. The subjects were told that in front of them was a special cognitive simulator that changed the field of vision. The simulator is equipped with a specialized video screen, which displays the image obtained with the help of a video camera. The specially designed conditions presented to the participants make it possible to increase the efficiency of cognitive processes in the framework of solving problems in experimental conditions. Then the test person sat down in front of the design of the simulator, located at the optimal distance from him, which allowed him to position himself with maximum comfort and freely move inside the body of the simulator, there was no need to change the position of the body during the experiment. The experimental part of the study took approximately 30–60 minutes, depending on the level of complexity of the task.

The experimental and theoretical part of the study was carried out on the basis of the General Education School «Integration» Tomsk, Tomsk region, Russian Federation. The participants of the study were students of 4th grade majoring in engineering. The sample included 6 children (4 boys and 2 girls aged 10 to 11 years). The participants took part in the study on a voluntary basis. We received signed informed consent forms from the parents. All participants did not have any contraindications for refusal to participate in the study.

At the first stage of the study, using the method of expert assessments (teachers, psychologists), psychological information was obtained for each person, including characteristics of relations with classmates, parents and teachers, behavioral characteristics, information about educational achievements and educational interests.

At the second stage of the study, a qualitative analysis of the video images obtained for each subject in the process of solving the "Tower of Hanoi" problem was carried out. During the analysis, an additional diagnostic protocol was created, including the analysis criteria for solving the Tower of Hanoi problem.

Results

During the analysis of the obtained results (Table 1), we can draw generalized conclusions on the selected criteria in three experimental conditions.

Table 1
Selected criteria for all subjects in three experimental conditions.

Mode	Criteria	Participants					
		P103	P213	P365	P491	P523	P648
No distortion of the visual field	Total time to solve the problem	15:13	19:59	16:53	13:53	8:30	8:57
	Total number of mistakes made	4	6	4	23	0	14
	Commented on their actions	+		+	+		+
	Executes instructions independently	+		+		+	
	Follows instructions with the help of an adult		+		+		+
	Avoids executing instructions				+		+
	Cannot master the rules of instruction on their own				+		+
	Returned to the initial stage of solving the problem			+			
	Completed the issue	+	+	+		+	
	Couldn't solve the problem				+		+

	Criteria	Participants					
		P103	P213	P365	P491	P523	P648
Visual fieldinversion	Total time to solve the problem	10:00	10:52	14:10	17:30	13:27	16:38
	Total number of mistakes made	5	7	6	20	4	15
	Slow motor actions	+		+	+	+	+
	Changes the position of a task		+		+		+
	Changes the position of the hands (right / left)			+			+
	Commented on their actions	+		+	+		+
	Executes instructions independently	+		+		+	
	Follows instructions with the help of an adult		+				
	Avoids executing instructions				+		+
	Cannot master the rules of instruction on their own				+		+
	Returned to the initial stage of solving the problem						
	Completed the issue	+	+	+		+	
	Couldn't solve the problem				+		+
	Criteria	Participants					
		P103	P213	P365	P491	P523	P648
Image time delay	Total time to solve the problem	5:36	6:22	6:50	8:19	10:14	12:28
	Total number of mistakes made	2	6	1	16	0	14
	Slow motor actions	+			+		+
	Changes the position of a task		+				+
	Commented on their actions				+		+
	Executes instructions independently	+	+	+		+	
	Follows instructions with the help of an adult				+		+
	Avoids executing instructions						+
	Cannot master the rules of instruction on their own						+
	Returned to the initial stage of solving the problem						+
	Completed the issue	+	+	+	+	+	
	Couldn't solve the problem						+

The total time for solving the problem and the number of students' mistakes made for all three experimental conditions are shown in Figures 2 and 3.

Figure 2
The total time for solving the problem for each subject in three experimental conditions

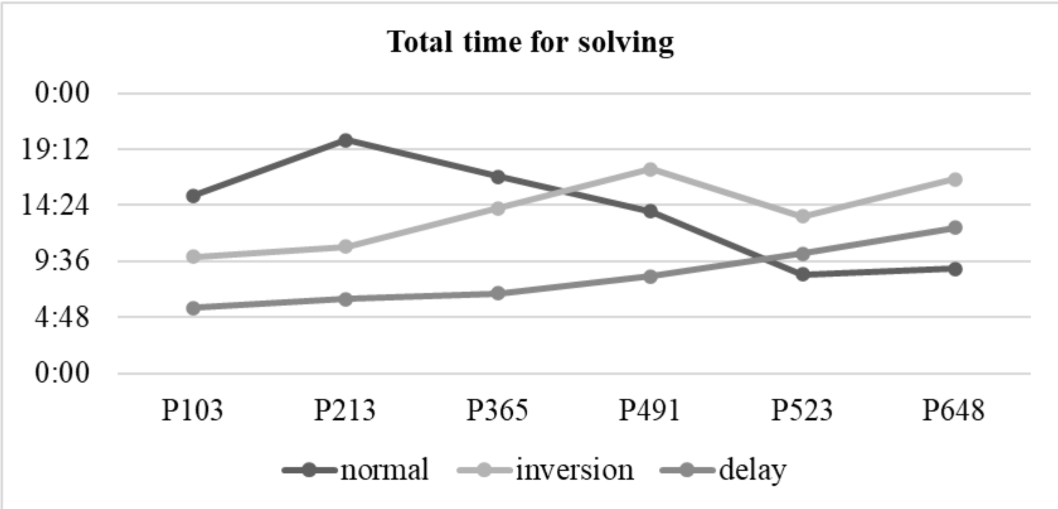
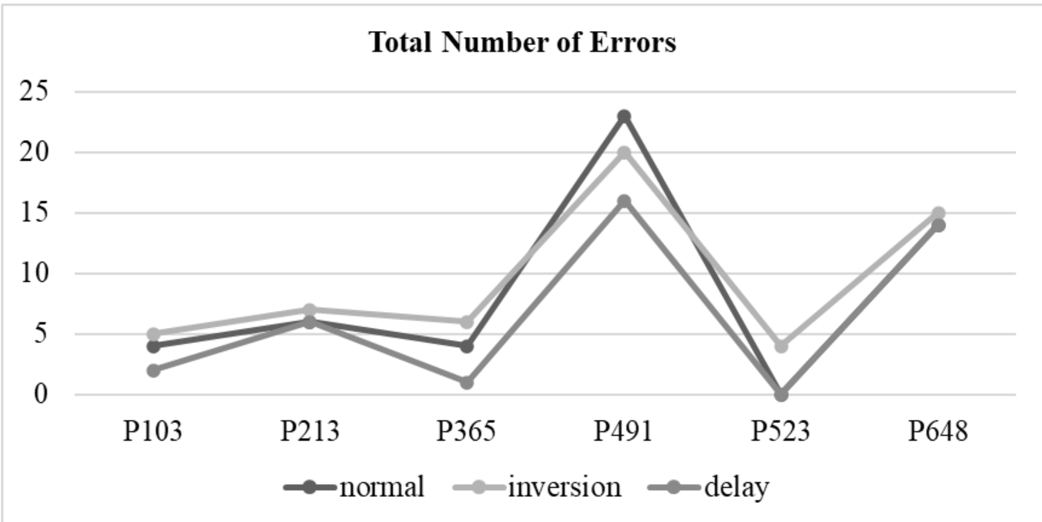


Figure 3
Schematic representation of committed errors in three experimental conditions



The results obtained during the qualitative analysis showed significant differences in individual indicators. For example, there is an extremely large spread in the time for solving the problem by the participants, differences in the number of mistakes made, the absence or, conversely, the ability to independently follow instructions and solve the problem, the speed of solving the problem, as well as different dynamics of motor activity. This study made it possible to check to what extent the conditions with the use of a cognitive simulator allow creating a situation of examination and emotional involvement of the subject. For us, it was necessary that the subject was emotionally involved in the process of solving the problem.

It should be noted that the subjects took the task proposed to them quite seriously and positively, emotionally reacted to the experimental conditions, the phrase was often noted: *"This is interesting, but I cannot solve it", "It is difficult to perceive the task", "The task is not solvable", "I really enjoyed solving the problem"*, etc. In addition, the subjects were interested in who else was participating in the study, what their results were, how quickly other subjects solved the problem, whether there were those who could not solve the problem. Also, several subjects, coming to the second and third stages of the study, began solving the problem with the phrase: *"I figured out how I can solve the problem faster", "I learned my moves"*, but at each stage of the study an additional new disk was added, which significantly complicated the task itself and the course of action.

However, there were test subjects who had never solved the problem, who at each stage of the study faced various difficulties. For example, without the experimenter's hints, they did not know how to solve the problem; they also had certain features, such as loss of orientation due to visual field distortion, and difficulty in determining the strategy for solving the problem. Some of the subjects explained the failure by the fact that they could not concentrate on solving the "Tower of Hanoi" problem due to the experimental conditions.

Below, as an illustration, descriptions of self-regulatory manifestations of subjects differing in the modality of sensomotor activity in the course of solving a cognitive task in three experimental conditions (without visual field distortion, with visual field inversion and time delay of the image) are presented.

Participant P103 at the first stage of solving the problem immediately understood the rules for solving the task, did not experience any difficulties in solving the problem, very often commented on his actions, constantly repeated the phrase "small disk to large", thus helping himself in solving the problem. The total time for solving the problem was 15 minutes 13 seconds. This participant had calm dynamics of motor activity and average speed of solving the problem. At the second stage of solving the task, he took the experimental condition rather hard, which was accompanied by a slow pace of solving the problem, as well as making mistakes. The test subject said that it was difficult for him to get used to the conditions, the inversion of the visual field greatly confused him in the space of the stage. In addition, the subject commented on his actions, thereby helping to solve the problem. The dynamics of motor activity in this subject was calm and the speed of decision making was average.

At the **third stage** of the study, he did not experience any difficulties, the delay of the images did not distract him from the decision in any way, since he relied on his tactile sensations. He solved the problem quite quickly – in 5 minutes 36 seconds. The subject had an active dynamics of motor activity and a high speed of solving the problem.

Test subject **P213** at the **first stage** of the study solved the problem for the longest time –19 minutes 59 seconds, made 6 mistakes. The participant did not immediately understand the rules of solution and, with the help of the experimenter, tried to figure them out, however, in the process of solving the problem, he refused prompts. The subject had chaotic dynamics and a low speed of solving the problem. At the **second stage** of the study, the subject solved the problem faster than at the first stage, despite the fact that the solution conditions and the task itself became more complicated. There were more mistakes than at the first stage. It was difficult for the test person to navigate in space due to the experimental conditions. It is worth noting that before starting to solve the problem, the participant said that he figured out how to solve the problem, but did not expect that an additional disk was added. There was an active dynamics and a high speed of solving the problem. At the **third stage** of the study, the subject solved the problem in 6 minutes 22 seconds. It is worth noting that the subject at first waited for the image delay to stop, then made his moves, but somewhere in the middle of solving the problem he began to rely on his tactile sensations, because he experienced complexity and intolerance to the image delay. There was a chaotic dynamics and average speed of solving the problem.

Test **subject P491** at the **first stage** of the study stubbornly did not follow the rules that the experimenter indicated to him, inventing his own, commenting on his actions, as if he wanted to hear approval from the experimenter. This subject made many mistakes, more than other participants. After the help of the experimenter, he continued to ignore the rules, saying the following phrases: *"The problem is not solvable", "It cannot be solved", "You are deceiving me", "I want to solve it in my own way"*. For the entire time of solving the problem – 13 minutes 53 seconds – I could not solve the problem. Additionally, it is worth emphasizing that by the end of the decision, there was a loss of motivation. The subject had chaotic dynamics and a low speed of solving the problem. At the **second stage** of the study, he experienced excitement, but at this stage, the subject was motivated to solve the problem. The inversion of the visual field greatly influenced the course of solving the problem, the test subject tried to adapt to the conditions by constantly changing the position of the tower. He commented on his actions, often saying one phrase: *"Here you have to think"*. The subject could not find the correct strategy for solving the problem, even with the help of the experimenter, and also made many mistakes. Without hints and leading questions, he could not solve the problem. For the total time of 17 minutes 30 seconds, he could not solve the problem. The dynamics of motor activity of this subject was chaotic and the speed of solving the problem was low. At the **third stage** of the study, the subject solved the problem, focusing on his hands. The time for solving the problem was 8 minutes 19 seconds, the number of errors was less than in the previous two stages. The subject was quite positively involved in the process of solving the task, he also relied on the help of the experimenter. At this stage, the subject managed to find the right strategy, and he was able to solve the problem. The subject had an average dynamics of motor activity and an average speed of solving the problem.

Participant **P648** at the **first stage** of the study could not understand the rules for solving the problem, commented on his actions, for the entire time of solving the problem – 8 minutes 57 seconds, he could not solve the problem, while making a large number of errors. The subject had a chaotic dynamics of motor activity and an average speed of solving the problem. The subject at the **second stage** of the study with the inversion of the visual field showed a lack of motivation, he indulged, could not sit still, did not want to solve the problem in the cognitive simulator, and almost cried because he didn't manage to solve the problem. He often changed the position of his hands, trying to help himself, holding the disks in his hand for a long time, thereby trying to deceive the experimenter and put the disks in the correct position. By the middle of solving the problem, he pulled the tower out of the cognitive simulator and refused to solve it further. In 16 minutes 38 seconds, he did not solve the problem, leaving it halfway through the solution. The subject had a chaotic dynamics of motor activity and a low speed of solving the problem. At the **third stage** of the study, everything was the same as at the second stage, i.e. there was a lack of motivation, the subject indulged, could not sit still, did not want to solve the problem in the cognitive simulator. When solving a problem with a time delay, he played with the regime, the motor activity was slow, the subject deliberately did everything slowly, thereby showing that he did not want to solve the problem in a cognitive simulator. After the experimenter asked to solve the problem without using the cognitive simulator, the subject also failed to solve the problem. This participant had a chaotic dynamics of motor activity and a low speed of solving the problem.

Discussion

The solution of the proposed cognitive task by younger students in specially designed conditions, such as visual field inversion and image delay in time, required the subjects to optimally use their sensory potential to determine the position and size of the discs, as well as balance muscle efforts to move the discs from one stem to another. In addition, the subjects had to use the self-regulatory resources of cognitive activity so that they could focus on the task, not be distracted by the surrounding objects, and not lose patience with unsuccessful attempts. In addition, solving the problem required analytical and strategic thinking from the subject, planning their actions. The test subjects had to understand how to move the disks in order to reach the goal. The proposed experimental plan for increasing the efficiency of recording the manifestation of features of sensorimotor activity when solving a cognitive task in specially organized conditions on a cognitive simulator made it possible to record the correspondence of invariant and variable features of sensorimotor activity of children of elementary school age, who have different experiences of educational achievements, and the features of self-regulation of cognitive activity. The obtained results provide grounds for creation of a developmental program for using this cognitive simulator to minimize existing self-regulatory deficits in cognitive activity of primary schoolchildren as one of the significant tasks of psychological and educational support for the cognitive development of modern children and adolescents (Popova, 2022; Barabash, 2023; Gagai & Efremova, 2019; Kukubaeva & Sadvakasova, 2021; Preobrazhenskaya, 2019).

The analysis of the results of the study allowed us to make several **generalizing statements**.

The **invariant** (independent of the individual psychological characteristics of educational activity, educational activity and behavioral characteristics of the subjects) features of the sensomotor activity of children of primary school age when solving a cognitive task include the following:

- When working on a cognitive simulator, the subjects were faced with the fact that they had to control their emotions and behavior when a difficult situation appeared while solving a problem, as well as show patience, perseverance and confidence in their abilities;
- Experimental conditions, such as distortion of the visual field and image delay in

time in the process of solving the problem, led to a violation of sensomotor activity, thereby complicating the process of solving the problem for the subject;

- Visual field inversion caused some perceptual changes, such as misorientation of objects in space, a feeling of unusualness and disorientation, and also led to a situation of perceptual uncertainty, since it disrupted the idea of how the task should look like.

The following are identified as variable features of sensomotor activity when working on a cognitive simulator:

Some subjects had problems with self-regulation, which were accompanied by a problem with sensomotor activity. For example, they showed hyperactivity, lack of confidence in movements, difficulty with attention and concentration on a task. They also experienced difficulty with emotion control and stress tolerance, which was associated with impaired sensomotor information processing;

- When solving a cognitive task, subjects with good motivation for learning and additional education, as well as good educational achievements, demonstrated a fairly high rate of sensomotor activity, found an effective solution strategy, applying it at all stages of the experiment;
- Junior schoolchildren participating in the study, who have problems with learning and demonstrate underdevelopment of the ability to control their emotions and behavior, were hardly able to build an effective strategy for solving the problem, having a large spread in time compared to others. None of them showed a high level of sensomotor activity.

Thus, the study allows us to make a conclusion about the possibility of using a cognitive simulator as a diagnostic tool for identifying the modality of sensorimotor activity of elementary schoolchildren as one of the significant psychological markers of self-regulation of cognitive activity.

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Tatyana Anatolyevna Vaulina – preparation of the text of the article, conducting research.

Author Details

Krasnoryadtseva Olga Mikhailovna – Dr.Sci. (Psychology), professor, Head of Department of General and Pedagogical Psychology Federal State Autonomous Educational Institution of Higher Education "Tomsk State University", Tomsk, Russian Federation; WoS ResearcherID: N -3017-2014; Scopus Author ID: 5719395360; RSCI Author ID: 166267; SPIN-code RSCI: 2357-7403; ORCID ID: https://orcid.org/0000-0003-1549-9994; e-mail: krasnoo@mail.ru

Eremina Evgeniya Valer'evna – Assistant, Department of General and Pedagogical Psychology, Federal State Autonomous Educational Institution of Higher Education "Tomsk State University", Tomsk, Russian Federation; WoS ResearcherID: GLV-4152-2022; Scopus Author ID: 57451881100; RSCI AuthorID: 1193748; SPIN-code RSCI: 8396-0032; ORCID ID: https://orcid.org/0009-0001-2037-3539; e-mail: eva.smeshko@mail.ru

Podoynitsina Mariya Anatol'yevna – Cand.Sci. (Psychology), Associate Professor, Department of General and Pedagogical Psychology, Federal State Autonomous Educational Institution of Higher Education "Tomsk State University", Tomsk, Russian Federation; WoS Researcher ID: F-3460-2014; RSCI Author ID: 838483; SPIN-code RSCI: 2965-5459; ORCID ID: https://orcid.org/0009-0005-0930-5040; e-mail: podojnicina@gmail.com

Vaulina Tatyana Anatolyevna – Cand.Sci. (Psychology), Associate Professor, Department of General and Pedagogical Psychology, Federal State Autonomous Educational Institution of Higher Education "Tomsk State University", Tomsk, Russian Federation; WoS ResearcherID: ABC-3850-2022; RSCI Author ID: 286384; SPIN-code RSCI: 1953-5811; ORCID ID: https://orcid.org/0000-0002-3837-3756; e-mail: tatvaulina@gmail.com

Conflict of Interest Information

The authors have no conflicts of interest to declare.