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**DIAGNOSIS OF THE LEVEL OF DEVELOPMENT OF
EXECUTIVE FUNCTIONS IN PRESCHOOL AGE**

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Abstract

The article considers Miyake's model of executive functions as applied to preschool age. The main objective of the study was to appraise the NEPSY diagnostic toolkit for assessing the level of executive functions development on a sample of Russian preschoolers (N = 267). As a result of comparing the results shown by US and Russian children aged 5-6 years, some specific cross-cultural features were identified: Russian children display a more developed image memory on average while their American peers showed a better memory for spatial representations. The speed of constraining control task performance averaged two times higher results in Russian preschoolers than in the Americans. To verify the convergent validity of the toolkit, a correlation analysis on a sample part (N = 48) was made of the results of the preschoolers' performance of two batteries of methods which was developed and tested under the guidance of L.A. Wenger. The revealed intercorrelation confirmed the possibility of using the above tools to diagnose executive functions. Analysis of the study data showed that the development levels of auditory and visual memory in older preschool children were not interrelated. However, in many respects verbal memory lies at the basis of attention flexibility development (switching), whereas visual memory underlies restraining control (inhibition). Based on the results of the diagnosis, four different variants of executive function development in the senior preschool age were identified and described.

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Keywords: Preschool age, executive functions, verbal memory, visual memory, attention flexibility, constraining control



1. Introduction

Development of voluntariness or executive functions is a major important achievement in the senior preschool age and a predictor of successful school adaptation and education (Blair, 2002; Welsh et al, 2010; Willoughby et al, 2012; Yeniad et al, 2013, etc.). Although there are methodological differences between the concepts of voluntariness (in the cultural and historical sense) and "executive functions" (neuroscience), the underlying processes are similar in both of them (Almazova et al, 2016).

2. Problem Statement

Let us dwell a little more on A. Miyake's model of executive functions (Miyake et al, 2000). According to this model, the neuropsychological basis for mastering one's own behavior is formed by a group of cognitive skills that provide targeted problem solving and adaptive behavior in new situations collectively known under the name of executive functions. They provide monitoring and control of thinking and activities through shifting the processes toward a stimulus associated with the task despite secondary tasks and interference. In neurocognitive studies, the inhibition process and working memory are considered as the main processes that ensure voluntary regulation (Blair, 2002; Solovieva & Quintanar, 2015; Verbitskaya et al, 2015).

Executive functions are divided into the following main components: working memory - visual and verbal, attention flexibility or switching (cognitive flexibility), which is associated with the ability to shift from one rule to another, and constraining control (inhibition), which involves the inhibition of a dominant response in favor of what is required in the task.

These components are related to each other, but they can also be viewed as being independent, separate from each other, that is why this model came to be called "unity-with-diversity". Despite the fact that this model was originally based on results obtained in adults, the possibility of its use in describing child development was also confirmed in the works by foreign researchers (Diamond et al, 2002; Diamond & Lee, 2011; Lehto et al, 2003; Visu-Petra et al, 2012).

3. Research Questions

In the above meaning, as a holistic construct, executive functions have practically not been studied in Russian psychology (Almazova et al, 2016).

4. Purpose of the Study

We selected and tested a diagnostic toolkit on a Russian sample to assess the development level of executive functions in older preschoolers (5-6 years).

5. Research Methods

To diagnose executive functions development, a set of four methods commonly used in foreign practice was chosen. Most of the methods used in the study are subtests of the NEPSY-II

neuropsychological diagnostic complex (Korkman, Kirk & Kemp, 2007), aimed at assessing the mental development of children aged 3-16 years.

The development level of working memory was measured by two methods:

- 1) The NEPSY-II Sentences Repetition subtest for verbal memory;
- 2) The NEPSY-II Memory for Designs subtest for visual memory.

Switching and inhibition were diagnosed using the following techniques:

- 1) Card sorting based on variable characteristics (Dimensional Change Card Sort (DCCS), (Zelazo, 2006);
- 2) The NEPSY-II Inhibition subtest.

Additionally, to screen out children with possible intellectual disabilities, Raven's color progressive matrices were used (Raven, Raven & Court, 1998).

Since all the methods except for the Raven progressive color matrices, are not widely used in Russian psychology, we will discuss them in more detail.

The Sentences Repetition subtest uses 17 sentences. The method has them organized in such a way that the complexity of the stimulus material increases gradually with sentences becoming longer and more complex in their structure. So, Sentence 1 for repetition consists of two words - "Good night", and Sentence 12 - "The woman standing next to a man in a green jacket is my aunt." Word omissions, replacements or additions are considered to be a mistake. Changes in word order, transfer of a word are also counted as a mistake. For each sentence a child is awarded 2 points if no mistakes have been made, 1 point for 1 or 2 mistakes, 0 points for 3 or more mistakes or in case no response was elicited from the child. If the child received 0 points for 4 sentences in a row, testing is discontinued.

With the help of the Memory for design subtest, two aspects of visual memory are simultaneously measured - memory for "images" (selecting pictures from a multitude of similar ones, as in the presented sample,) and spatial representation (selection of a place where the cards were located in the sample). In each task one point is awarded for each correctly selected card, one point for each correctly specified place taken in the standard sample and two bonus points for each complete match to the standard sample (a correctly selected card placed in the right place). Thus, the performance on the methods results in making several assessments - memory assessment: 1) for images, 2) for spatial arrangement; 3) for the combination of both.

The Dimensional Change Card Sorting method contains three series of tasks. In Series 1 a child sorts out 6 select cards based on color (red objects are put to one side, blue ones are put to the other). In Series 2 sorting is done "by shape" (6 cards, boats are put to one side, rabbits to the other). In Series 3 the child is to sort out 12 cards based on either the shape or color of the target card by focusing on the external stimulus for color or shape - the presence or absence of a black border on the card. In each series, one point is given for each correct answer.

Switching from the tasks of the first series to those of the second series is indicative for assessing the development level of switching in 3-4 year olds. By the age of 5-6, an absolute majority of preschool children are able to cope with this test. Although we assess the number of correctly piled cards in each series, the decisive factor in determining the development level of switching in the senior preschool age is the score received by the child in Series 3.

The Inhibition method consists of two parts - naming and inhibition proper. A series of 40 geometric figures (squares and circles) is presented. At the first stage, a child is asked to name all the figures in the order in which they appear on the card. At the second stage, the rules change: when the child sees "a circle" he should say "a square", and when he sees "a square" – he is to say "a circle". Training is provided for each of the parts. The experimenter records the time it takes the child to do the task, the number of mistakes made and the number of self-corrections.

6. Findings

6.1. The sample and the study procedure

The study sample included 267 children aged 5-6 years (Me = 5.6 years, CD = 0.3) who attended the older group in Moscow kindergartens. Of these, 143 were boys and 124 were girls. This study was conducted in the 2016 school year. The examination was carried out on an individual basis, in a quiet room. All the tasks were presented to a child in a play form, which ensured a high degree of the child's involvement in its fulfilment. Two 15-20 minute long meetings were held with each child. The authors of the NEPSY-II diagnostic complex impose the following limitations on children who participated in the study during the standardization of the methodological complex. A child was excluded from the study if he or she:

- 1) Had undergone any other neuropsychological examination in the previous 6 months;
- 2) Had (uncorrectable) auditory or visual impairments or was color-blind;
- 3) Had a psychiatric diagnosis, neuropsychological disorders, attention deficit, hyperactivity, intellectual retardation;
- 4) Was born with a very low birth weight (less than 2.5 kg);
- 5) Was taking medications (stimulants, antidepressants, medications for anxiety, etc.) that could affect the results at the time of the study;
- 6) had had a recorded loss of consciousness for a duration of more than 5 minutes, a coma condition (up to 14, according to the Glasgow scale), etc.;
- 7) had difficulty with the language in which the research was being conducted or the language was the child's native tongue (language difficulties exclude the articulation problem providing the latter does not hinder communication with the child) (Korkman, Kirk & Kemp, 2007).

Of these Conditions numbers 4, 5 and 6 were outside our control. The level of intellectual development, or to be more precise, the absence of deviation from its norm, was tested by using the Raven Color Progressive matrices.

6.2. General data analysis

With the help of the Raven color progressive matrices preschool children with suspected cognitive development deviations (3 preschoolers) were excluded from the study.

Table 1 presents the main psychometric characteristics of the results of administering the methodologies to assess the development of different executive function components, obtained during our study and adaptation of the set of NEPSY-II techniques (US standards).

By using the above table, it is possible to single out general trends and specific features of administering the methods on different samples:

1) We believe that the small difference in the average score according to the Sentences Repetition method is explained not so much by the difference in the development level of auditory memory but by a slight difference in the complexity of sentence structures in the Russian and English versions.

2) Memory for design. The average score for image reproduction is higher in Russian children whereas that for spatial reproduction is higher in American preschoolers. At the same time, the average overall score tends to be higher in Russian preschool children. That is to say that the images themselves are more accurately remembered by Russian preschoolers on the average, while spatially they are better located by their US peers, which is most likely due to the difference in educational programs. A big difference in the average overall scores suggests that Russian children's performance on the task tended to be well in all respects, i.e., they reproduced both correctly selected objects and their place in the field thus allowing them to receive maximum possible bonus points.

3) Although there are no data on the main psychometric characteristics of the DCCS method present, but the data of the author's most studies show that by the age of six, about half of children start coping successfully with the last method test (scoring 9 or more points out of 12), 38% of our preschool respondents coped with this unit. Thus, we can talk about the proximity of the results using this technique.

4) The most profound differences between Russian and American children aged 5-6 years were found after comparing the results of the Inhibition method. The average time which the Russian children spent doing both Test 1 and Test 2 is almost half the time it took the American children to do the same task. We can account for this by differences in the social situation of the children's development: Russian children attend kindergartens while their American peers go to school. This may impact their approach to task performance. The position of being a schoolboy imposes a great responsibility on the child for the result, which consequentially results in considerable time costs.

Table 01. The basic psychometric characteristics of assessing executive function components in Russian and US preschoolers

Executive Functions Methods	Country			
	Russia		USA	
	Me	SD	Me	SD
Memory for Designs, Content (MfD_C)	39.5	6.2	31.5	6.1
Memory for Designs, Spatial (MfD_S)	16.6	6.7	19.2	6.3
Memory for Designs, Total Score (MfD_TS)	79.9	23.4	63.4	22.6
Sentence Repetition (SR)	19.6	4.3	17.2	5.4
DCCS, PreSwitch (DCCS_Pr)	5.9	0.3		
DCCS, PostSwitch (DCCS_Ps)	5.5	1.2		
DCCS, Border (DCCS_B)	7.5	2.9		
DCCS, Total Score (DCCS_TS)	18.9	3.5		

Naming, Time (Nam_T)	44	11	93	31
Inhibition, Uncorrected errors (Inh_UE)	3.1	5.3		
Inhibition, Corrected errors (Inh_CE)	1.9	1.6		
Inhibition, Time (Inh_T)	61	15	125	27

Let's return to the outcomes of our study. Gender differences in the results of all the methods administered were checked using the Mann-Whitney test for two independent samples. It was found that girls performed significantly better card sorting tasks on shape ($U = 7906.0$, $p = 0.001$) and made significantly fewer mistakes (both corrected and uncorrected) in the inhibition trial ($U = 7103.5$, $p < 0.000$ and $U = 7859.5$, $p = 0.020$).

Table 2 shows the results of the correlation analysis of data obtained through different methods of the complex using the Spearman correlation coefficient.

First of all, let us dwell on the links between the results of the tasks for diagnosing the development level of various executive function components.

When administering a visual memory checking method image memory proved to be associated with the time it took to perform two trials in the Inhibition method. In other words, the better an image is remembered, the quicker the job of figure-naming and its inversion proceeds.

The results obtained during the administration of the Sentences Repetition method turned out to be related to different parameters of the DCCS method, which may, for example, indicate that a well-developed verbal memory helps to better understand instructions.

With regard to the relationship between the results of the inhibition and switching techniques, the number of uncorrected mistakes is connected (reversely) to the success of the third switching task (the DCCS), and the naming time is related to the success of the first two switching tests.

Table 02. Connections between assessments of various indicators of administering techniques aimed at diagnosing executive functions in preschool children

EF	1	2	3	4	5	6	7	8	9	10	11	12
1.MfD_C	r p	1 .	0.492 0.000	0.817 0.000					- 0.116 0.064			- 0.128 0.041
2.MfD_S	r p		1 .	0.828 0.000		0.130 0.039						
3.MfD_TS	r p			1 .	0.135 0.033							
4.SR	r p				1 .	0.117 0.050	0.193 0.001	0.196 0.001				
5.DCCS_Pr	r p					1 .		0.181 0.003	0.130 0.034		0.122 0.047	
6.DCCS_Ps	r p						1 .	0.134 0.040	0.353 0.000	0.121 0.048		
7.DCCS_B	r p							1 .	0.954 0.000		- 0.113 0.066	
8.DCCS_	r								1		-	

TS	p									0.159		
										0.009		
9.Nam_T	r								1	-		0.458
	p									0.175		0.000
										0.004		
10.Inh_UE	r									1	0.161	
	p										0.008	
11.Inh_CE	r										1	0.124
	p											0.040
12.Inh_T	r											1
	p											

The assessments within the methods proved to be interrelated, which is the result we expected.

6.3. Convergent and constructive validity of the toolkit

Convergent validity assessment was carried out by calculating on a part of the sample (N = 48 - 24 girls and 24 boys) the correlation between the results obtained by using the above methods and those of the preschoolers' performance on the battery of the techniques developed at the Wenger laboratory (Wenger et al, 1986). These tools were used because they are widespread in Russia, and also due to the fact that Vygotsky's cultural-historical approach lies at the basis for constructing a methodology of methodological tools and special attention is paid to the development of voluntariness through mastering visual modeling means (Wenger et al, 1986).

The following methods were introduced:

1. The *Template* method (Wenger, Kholmovskaya, 1978) enables researchers to determine the perception development level in children of the older preschool age, viz. the ability to correlate sensory templates of shape with real objects.
2. The *Systematization* method (Wenger, Kholmovskaya, 1978) shows how well a preschooler can perform such actions of logical thinking as seriation and classification.
3. The *Schematization* method (Wenger, Kholmovskaya, 1978) reflects the level of the child's mastery in visual modeling activities: when doing the tasks a child uses a conventional and schematic image as a sample or rule and to achieve a positive result he needs to strictly follow a given sequence of reference points. Thus, execution of this task involves processes of perception, visual and image thinking, voluntary attention and the child's regulation of its own activity.
4. The *Least Likelihood* method (Wenger et al, 1995) allows you to study the development of perception and thinking in children. It helps to assess the level of their mastery of such mental operations as analysis, comparison and generalization of characteristics.
5. The *10 Words* and *10 Objects* memorization methods (Wenger et al, 1995, Marzinkovskaya, 2010, respectively) which help to determine the development level of auditory and visual working memory.

The comparative research showed that the results of conducting both diagnostic sets correlate well enough with each other and make it possible to see the contribution of memory and voluntary attention development to the successful performance on tasks aimed at studying executive functions. For example, the number of mistakes a child makes when doing a naming task according to the *Inhibition* method was

found to be associated (reversely) with the results of most of the techniques used to diagnose how well a child has mastered the sensory templates and the level of development of its visual and image thinking (*Templates* = 0.359, $p = 0.015$), *Systematization* ($r = -0.315$, $p = 0.042$), *Schematization* ($r = -0.342$, $p = 0.022$)). And this, in turn, speaks about the connection between the notions about constraining control, as a component of executive functions and voluntariness of thought processes, according to Wenger's theory of abilities.

The connection between the results of the methodologies of *The Least Likelihood* and the DCCS ($r = 0.402$, $p = 0.006$) may indicate that at the basis of the administration of both methods lies the ability to focus on the properties of an external template for improving one's actions.

The results of the methods used to diagnose the level of auditory and verbal memory development *10 Words* and *Sentences Repetition* proved to be related ($r = 0.328$; $p = 0.028$). While the results of the *10 Objects* and *Memory for Design* methods turned out be partially related: the results of the *10 Objects* method are associated only with one of the aspects considered in the Memory for Design technique, viz. image memory ($r = 0.402$, $p = 0.006$). This allowed us to conclude that *Memory for Design* yields more diagnostic data than *10 Objects*.

Thus, we can speak about diagnosing voluntariness with the help of these methods noting a profoundly detailed development of various aspects of executive functions using methods that have been elaborated abroad.

To check that the *Sentences Repetition* method enhances its task complexity gradually, the results obtained in each of the questions were compared. The outcome of this work was moving some of the sentences up or down the list for further work with the method. So, for example, Sentence 14 "Teenagers in our house are collecting money for the construction of a recreational center" proved to be significantly more difficult for preschool children than Sentence 15 "We put the picnic food back into the basket because of the approaching storm" (Wilcoxon's test for two dependent samples, $W = -5.808$, $p < 0.000$). In this connection, at the next stage of standardization, the order of sentence presentation will be slightly changed.

6.4. Typology of executive function development in the older preschool age

A sufficiently large spread of data in the performance results on methods for diagnosing the level of executive function development (Table 1) allowed us to suggest a possibility of constructing a typology of executive function development in preschool children aged 5-6 years. With the help of a cluster analysis (the k-means method) of the data on all the methods under consideration, the respondents were divided into 4 groups (the number of groups was determined empirically). Table. 3 shows the centers of the cluster types obtained (weighted averages).

Table 03. The cluster centers according to all the assessments of the executive function components.

Executive Functions Methods	Cluster			
	1	2	3	4
Memory for Designs, Image (MfD_I)	35.89	35.98	42.55	44.11
Memory for Designs, Space (MfD_S)	13.32	12.76	21.11	21.34

Memory for Designs, Total Score (MfD_TS)	65	61	97	101
Sentence Repetition (SR)	21	19	20	21
DCCS, PreSwitch (DCCS_Pr)	6	6	6	6
DCCS, PostSwitch (DCCS_Ps)	5	5	6	6
DCCS, Border (DCCS_B)	8	7	7	7
DCCS, Total Score (DCCS_TS)	19	19	19	19
Naming, Time (Nam_T)	65.5	41.4	49.6	37.8
Inhibition, Uncorrected errors (Inh_UE)	5.2	3.6	1.9	3.4
Inhibition, Corrected errors (Inh_CE)	1.9	1.9	2.4	1.8
Inhibition, Time (Inh_T)	94.1	57.6	70.6	51.0

Using the Kruskal-Wallis criterion for several independent samples, we checked whether there are significant differences in the assessments of preschoolers in different groups. Significant differences are observed on the basis of the results of all the methods except the DCCS. Note that it is this method that has the least relative spread of data. Let us describe the resulting groups of preschool children in more detail.

Type 1 (12% of the sample). Preschoolers who fell into this group have rather low assessment of visual memory development, spend much time on doing the naming and inhibition tests and make quite a few mistakes which they fail to correct. Verbal memory is well-developed.

Type 2 (41% of the sample). Respondents in this group have low assessments of their visual memory development; they are quick to do the naming and inhibition tests. At the same time they make many mistakes in the inhibition test, most of which they fail to correct. The preschoolers' auditory memory in this group is worse than that of the other children.

Type 3 (18% of the sample). The preschool children in this group have high assessments of their visual memory development. The time costs in doing the naming and inhibition tests correspond to the average. At the same time, a minimum number of mistakes are made and most of them get corrected. The development of auditory memory is at the average level.

Type 4 (29% of the sample). The respondents who got into this group received the highest marks when being tested on visual memory development. Their verbal development is also at a high level. The time costs when doing the naming and inhibition tests are the least of all compared to the other groups. In this case, the mistakes in the inhibition test (the number of mistakes is at the middle level) tend to be uncorrected rather than corrected.

Another important thing is the difference between Types 3 and 4 of executive function development in preschool children. Type 3 preschoolers prefer to take more time in an effort to avoid mistakes, whereas children of Type 4 are more inclined to get the task done as quickly as possible without caring much about the accuracy of the result obtained.

7. Conclusion

The paper presents the first stage of adapting and standardizing a set of techniques aimed to diagnose the level of executive function development in older preschoolers in order to study its main components.

A comparative analysis of the results obtained by Russian and American preschoolers was conducted. Their common and distinct features were identified which can be explained by the difference in the education systems and a child's experience. So, for example, the development level of memory for images (pictures) proved to be higher in Russian senior preschoolers while their American peers surpassed them in spatial representation memory. Also, the study found a big difference in the amount of time preschoolers in both countries spend on fulfilling the inhibition tasks. It takes Russian preschool children almost half of the time to do the task which in our opinion is due to the different social positions they occupy; in the USA, 5-6 year-olds go to school whereas in Russia they attend kindergarten, which lays different claims on the quality of task performance.

As a result of testing the relationships between the results of administering different methods, the development levels of verbal and visual memory are correlated. In this case, auditory memory ensures the successful performance of switching tasks in a greater degree, while visual memory is more beneficial for inhibition tasks. The levels of development of switching and inhibition have proved to be correlated.

To test the convergent validity of the methodical complex, the results of preschoolers' performance on the two batteries were compared (on a part of the sample): the first was the subject in this study and the second was developed in the Wenger laboratory. A large number of links confirm the legitimacy of using the selected complex to diagnose the level of executive function development.

To obtain a more comprehensive picture of options for developing executive functions in older preschoolers, the respondents were divided into four groups. Each group's specific features and numerical composition were described. With a sufficiently high level of executive function development it is possible to see two main strategies for the task performance being formed: the first aims to do a task in the fastest possible way whereas the other aims to be mistake-free.

Already at this stage it is possible to see the diagnostic capabilities of the tools that are proposed for consideration and are aimed at diagnosing the level of executive functions development. After introducing minor changes in the materials and using stricter control over children's age during the administration of each of the methods, the next stage of research will develop standards for a Russian sample. In addition, it is planned to rerun a test based on similar materials and to control such variables as the tester's identity, the geographical location of kindergartens, etc.

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