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Neuropsychological Parameters of Graphomotor Skills in Typically Developing Children

Neli Vasileva

Department of Speech and Language Pathology, Sofia University "St. Kliment Ohridski", Sofia, Bulgaria
Email: vasnel@abv.bg

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Abstract

The relevance of the problem of specific learning disorders is becoming greater due to their increase among school-age children. The issue of their prevention is insufficiently discussed, which explains the limited number of studies on preschool children who are about to enter school. Delineating their neuropsychological profiles is important for deriving age norms for the development of basic mental functions, as well as for predicting future obstacles in the literacy process. The reason for this is that the preschool period has a specific sensitivity to the specialization of the cerebral hemispheres and the formation of the morpho-functional basis of higher psychic functions. Graphomotor skills are a basic phenomenon in preschool age, and their development implies a complex integration of programming, executive and spatial functions. According to literature, deficits in graphic functions are part of the developmental dyslexia syndrome. **Purpose of the Study:** To analyze the dynamics of neuropsychological mechanisms in the formation of motor graphic programs in the preschool period (4-, 5- and 6-year-old children). **Hypotheses:** 1) The age factor has a leading importance for the development of cerebral mechanisms and for the dynamics of graphomotor functions during the preschool period; 2) Children with typical development demonstrate different levels of graphic skills determined by the influence of social conditions and individual dynamics in the development of brain mechanisms of motor programs. **Method:** Neuropsychological graphomotor test "Fence", assessing the serial organization of movements and the ability to master a kinetic program. **Participants:** The study included 365 children with typical development, divided into three age groups—4-, 5- and 6-year-old. Along with the influence of the age factor, the influence of gender and demographic conditions (type of settlement) is also taken into account. **Results:** Criteria for outcome assessment included quality of serial movement organization, state of executive functions (mastery, degree of program formation), visual-spatial organization, and motor pauses. The pooled individual group scores were subjected to analysis of variance, which showed statistically significant influence of all three factors: age, demographics, and gender. The hypothesis of positive age dynamics of children's graphomotor skills, most pronounced at age 5, is confirmed. Despite the trend towards improvement in serial organization and coordination of manual movements, only 18% of children at age 6 years were fully proficient in the graphic test. The large differences in individual results are the basis for separating subgroups by state of graphomotor skills and different level of readiness for schooling. **Conclusions:** The age period 4 - 6 years is sensitive for the formation of the serial and spatial organization of children's graphic skills as predictors of successful school learning. The graphomotor test "Fence" is an objective and convenient method for diagnosing complex motor functions in the preschool period and a criterion for identify children at risk of learning difficulties.

Keywords

Child Neuropsychology, Preschool Age, Graphomotor Skills, Serial Organization of Movements, Executive Functions, Heterochronic Development, Predictors, Developmental Dyslexia

1. Graphomotor Functions in the Context of Child Neuropsychology

Graphomotor skills are one of the leading phenomena in child development in the preschool period and are identified as one of the conditions for full-fledged learning in school. Their neurophysiological organization corresponds to the elaboration of functional systems of connections between a large number of brain areas (cortical and subcortical) with the leading participation of the premotor departments of the left hemisphere. External markers of the state of motor programs include the child's graphic skills. These begin with the first attempts at graphic representation of individual elements, progress through activities of copying and drawing objects independently, and end with the mastery of complexly organized serial movements to spell words.

In recent decades, child neuropsychology has made significant advances in theoretical, diagnostic, and applied aspects, which explains the increased interest in neuropsychological research among a wide range of professionals in the field of typical and atypical child development. Akhutina (2006) notes that this development has led to the delineation of subdivisions, one of which is the neuropsychology of individual differences, the study of which is aimed at both inferring patterns and norms in child development and at uncovering "soft" forms of developmental disorders and early prediction of children at risk for learning disabilities.

An additional contribution is the use of neuroimaging data to complement and objectify the results of classical neuropsychological diagnosis. The variety of neuropsychological diagnostic methods with high predictive value is increasingly moving away from their traditional application in developmental disorders to the population of typically developing children. The reason for this is the variety of normative variants combining signs of delayed formation of individual functions with those of anticipatory and/or typical development.

The principle of heterochrony in the maturation of the brain mechanisms responsible for the development of basic mental functions at an early age determines the central place that functional diagnosis occupies in child neuropsychology. The specificity of this type of diagnosis is related to the differentiation of primary (central) symptoms and the resulting additional (secondary) symptoms of impaired development, followed by their association into a general neuropsychological syndrome with clear nosological parameters. Among the main tasks of neuropsychological diagnosis is the assessment of the child's readiness for school. This determines its place as a valuable prognostic tool that informs about the child's developmental strengths and weaknesses. At the same time, the majority of research in the field of child neuropsychology focuses on the school period, when the picture of learning difficulties and associated dyslexic symptomatology is clearly defined. The thesis of early diagnosis of possible learning difficulties is gaining wider support among professionals. This is drawing attention to the preschool period as a time of active maturation of the neurophysiological and neuropsychological prerequisites for learning. In our opinion, the determination of normative trends in neuropsychological development at this age has the greatest prognostic and socially significant value, since early detection of deficits in the maturation of mental functions involved in the functional systems of academic skills (reading, writing and arithmetic) is a condition for timely therapy and reduction of negative repercussions in children's learning.

As stated, among other higher functions, graphomotor skills (drawing lines and geometric shapes) are among the most important for assessing school readiness in preschool. They are a dynamically evolving and supramodal in nature and organization mental phenomenon. The basis for their formation is rooted in early psychomotor development, within which representations of one's own body ("body schema") are integrated with visual-spatial orientation. Successful mastery of graphomotor skills is the foundation of mastery of writing. Much of the literature considers the state of graphic skills in the preschool period as a predictor of future difficulties in learning and the development of dyslexic symptoms (in particular, disorders of the writing habit).

In the preschool period (up to the age of 6), the only form of graphic activity as a way of transmitting information from the child is drawing. Gradually, with the complexity of the neural networks of the brain and improved intellectual capabilities, it began to show interest in the written signs of the language. In this context, Vygotskij's (1983: p. 191) very precise formulation is that the child's mastery of writing is preceded by a stage in which he "makes a fundamental discovery, namely: not only objects can be drawn, but also speech". It should be added that in the process of mastering writing, graphomotor acquires the character of a highly conscious and strictly programmed activity.

In addition to being based on the coordination of eye and hand movements (visual-motor coordination), their implementation is directly related to the state of executive functions. The term "executive functions" represents the ability to consciously regulate one's own activity and behavior—goal formulation, activity planning, inhibitory control, goal-directed search for objects and appropriate ways of acting. According to experimental data (Fincham, Carter, van Veen, Stenger, & Anderson, 2002), the neural mechanisms that provide control and planning of behavior activate fronto-parietal areas (especially the right dorsolateral prefrontal cortex), bilateral parietal areas, and bilateral premotor areas.

Emphasizing the connection of executive systems with circular interactions between the frontal lobe and some subcortical structures (mediodorsal nucleus of the thalamus), Semenova, Koshelkov, & Machinskaia (2007) associated the most significant qualitative transformations in executive functions with the preschool and elementary school years. In the mentioned development, a number of sensitive periods in the development (neuro morphological and neurophysiological) of the functional executive system are outlined, each of which is associated with qualitative changes in its structure:

- First sensitive period—8 months of age; coincides with morphological changes in the frontal cortical departments (growth of dendritic fields, increase in the number of synaptic connections), which lead to visible changes in the child's psyche and behavior;
- Second sensitive period—2 - 3 years of age; significant morphological transformations in horizontal and vertical neural interactions of frontal regions are registered; their active participation in various functional systems begins, among which the system of visual perception takes the leading place;
- Third sensitive period—preschool and elementary school age (5 - 8 years); the growth of associative layers accelerates, the volume of neurons increases, the density of neuronal groupings increases, basal dendritic complexes are actively formed in different fields of the frontal cortex. Neurophysiological studies (Matchinskaia, Lukashevich, & Fishman, 1997) report EEG data on functional maturation of the fronto-thalamic regulatory system and active formation of neural connections of frontal cortical with subcortical brain regions. At the end of the period, the specialization of the frontal areas and their participation in the realization of mental functions significantly increases, which explains the qualitative changes in cognitive functions in children aged 7 - 8 years;
- Fourth sensitive period—(9 - 10 years); the system of neural connections and the structure of the associative layers of the cortex is complicated; the myelination of the frontal lobe is completed, which increases the activity of its regions (especially the prefrontal lobe) in the conscious behavior of the child. At the end of the period, some components of executive functions (goal-directed search, hypothesis testing, inhibitory control) reach the level of adulthood.

The presented periods confirm the thesis of the direct dependence of graphemotor skills on the state of executive functions, and their relationship with the sequential organization of movements defines them as one of the key moments in the neuropsychological development in the preschool and school period. This is justified by the large number of data on low performance on graphic tasks by dyslexic students. Therefore, along with other mental phenomena (gnosis, language, memory), graphemotor functions have undeniable predictive value in terms of readiness for learning.

Studies by some researchers (Kornev, 1997; Kirkwood, Weiler, Holmes-Bernstein et al., 2001; McPhillips & Sheehy, 2004; Berninger, 2004; Berninger, Nielsen, Abbott, Wijsman, & Raskin, 2008; Kuzeva, 2017) reported lower levels of performance on some motor patterns related to fine finger movements (fine motor skills/dexterity), redrawing complex shapes, graphic motor coordination, and automatic writing in children with dyslexia compared to normally developing children.

Nicolson and Fawcett (1994) cite data from research by J. Augur that many parents of students with dyslexia report difficulties in acquiring motor skills in their children's early childhood.

Viholainen et al. (2006) present experimental data confirming that reading deficits in children are associated with low motor development. The authors hypothesize a link between delayed motor development and expressive language abilities.

McPhillips and Sheehy (2004) examined children with a family history of dyslexia and found persistence of motor difficulties as well as the presence of some asymmetric primitive reflexes. Motor disorders most often refer to impaired coordination and deficits in gross and fine motor skills. Special attention is paid to the state of visual-motor coordination, which is defined as a comorbid indicator for the identification of dyslexia and for the development of writing skills.

Semenova et al. (2007) indicates that students who have learning difficulties show an obvious delay in the development of executive functions, which undergo qualitative transformations in preschool and elementary school age, associated with accelerated growth of associative layers in the frontal cortex, an increase in the volume and density of neural networks. Although the free switching from one action to another becomes possible in the period of 4 - 4:6 years, but its refinement undergoes a long development. At the end of the preschool stage (6 years), programming and controlling functions are not fully developed, they continue to improve and achieve stabilization no earlier than 9 years of age.

EEG-data from neurophysiological studies register significant changes in bioelectric brain activation during the period 5-8 years, which are associated with an increased influence of the frontal cerebral cortex on other cortical areas (Matchinskaia et al., 1997). When studying a target group of dyslexic students, Kornev (1997) assessed the levels and speeds of a number of neuropsychological parameters: lateralization of sensorimotor functions, visual-spatial orientation, skills for drawing geometric shapes and writing graphic signs (letters, numbers).

He defines the delayed development of the mentioned parameters as pathognomonic for cases of dyslexia and explains them with pronounced dysfunctions of the complex forms of visual-motor coordination. According to Kornev "...the deficit of pictorial and graphic abilities has a significant role in the pathogenesis of dyslexia, especially at the stage related to learning the representation of phonemes through letters and letter combinations" (p. 96).

Kuzeva (2017) conducted a neuropsychological study of 1st and 3rd grade students divided into typically developing and learning disabled groups. The study aims to analyze the relationship between the state of graphomotor functions and writing skills using a computerized version of a graphic test (reproduction of a graphic model). The status of serial organization of movements (programming and smooth transition between graphic elements), of executive functions (programming and control of movements), and of neurodynamic characteristics during task performance (speed and impulsivity) are assessed. Analysis of the results showed significant differences between groups on both tasks. All students with learning disabilities had marked difficulties in automating graphic habits and in writing skills. For children in Grade 1, the difficulties were complex in nature and were associated with low values on the serial organization, programming and control, and neurodynamics indices. In Grade 3 pupils, low scores on the graphing task were due to delayed neurodynamics, while difficulties in writing remained associated with impairments in executive functions.

All of the above facts point to the significant role of motor deficits in the development of dyslexia and highlight the need to diagnose children's graphic skills before they enter primary school.

Furthermore, the assessment of graphic motor skills is an important task due to the common combination of reading and writing problems within developmental dyslexia. This has led some authors to support the idea of integrating neuropsychological with traditional approaches that speech-language pathologists use in the analysis of reading and writing disorders. In a study based on such an integrated approach, Akhutina, Babaeva, Korneev, & Krichevets (2008) distinguished three forms of dysgraphia resulting from deficits in different brain functions: regulatory dysgraphia, acoustic-articulatory dysgraphia, and visual-spatial dysgraphia.

In relation to the topic of our study, of particular interest is the regulatory form, seen as a consequence of delayed development of premotor areas of the frontal lobe. Its symptoms include simplification of the motor graphic program, inert repetition of individual items, and impaired inhibitory control.

The theoretical paradigms and empirical data outlined highlight the need for in-depth investigation and assessment of graphemotor skills in the typically developing preschool population. This aligns with the goal of the present study, which is consistent with the trends of the neuropsychology of individual differences—to identify subgroups of children with varying degrees of school readiness according to their level of graphemotor skills. A description of the applied neuropsychological test (sample), the results of the statistical analysis of the data, and comments on the performance of the task by the different subgroups of children divided by age and social background are presented.

2. Organization of the Research

Objectives of the study:

1) Evaluation of the dynamics in the development of graphomotor skills (automation of motor programs and controlling functions) in typically developing preschool children (4-, 5- and 6-year-old); 2) Analysis of the interaction of biological and social factors for the process of forming graphic functions.

Working hypotheses:

1) The age factor has a leading importance for the development of cerebral mechanisms and for the dynamics of graphomotor functions during the preschool period;

2) Children with typical development demonstrate different levels of graphic skills determined by the influence of social conditions and individual dynamics in the development of brain mechanisms of motor programs.

Method and procedure:

For the purposes of the study, the neuropsychological sample "Fence" was used, which is part of the Neuropsychological Diagnostic Battery for Children, section "Serial organization of movements" (Akhutina, Polonskaya, Pylaeva, & Maksimenko, 2012). According to the authors, it assesses the ability to learn a graphic-motor program and automated transition between its elements and the state of visual-motor coordination.

The research procedure involves drawing on a graphical model of two connected alternating elements (**Figure 1**). The model is pre-drawn on a white sheet and, once given to the child, the child is asked to continue drawing the same "fence" to the end of the sheet. The condition is to observe the order of the elements and not to lift a hand during the drawing. The quantitative assessment of individual performance is based on 5 indicators: for serial organization, for programming and control, for visual-spatial functions, for pauses during drawing, and for muscle tone.

The test is conducted individually with each child. The maximum possible score for each examinee is 14 points, summed from the scores on the individual parameters of each of these indicators:

1) Serial organisation:

- normal performance—5 points;
- compensatory drawing—the elements of the pattern are in the correct order, but of different sizes—4 points;

Figure 1. Model of the graphic test for serial organization of movements "Fence".

- incorrect execution of the program (distortion of the elements)—flat vertical lines, curved corners—3 points;
- drawing on elements—with pauses and lifting the hand—2 points;
- appearance of superfluous elements (expansion of the programme)—1 point;
- inert repetition of an extended or simplified program—0 point.

2) Programming and Control:

- accurate execution—2 points;
- draws only one element of the program or inserts an additional—1 point;
- "escape" from the program (draws a straight or broken line)—0 point.

3) Visual-spatial functions:

- performance does not go beyond the line—4 points;
- elements are placed along the top or bottom line of the line—3 points;
- elements go slightly out of line—2 points;
- elements go significantly (about 45 degrees) out of line—1 point;
- items are angled more than 45 degrees—0 point.

4) Muscle tone:

- no increase or decrease in muscle tone—3 points;
- slight tendency towards micro- or macro-graphy—2 points;
- pronounced tendency to micro- or macro-graphy—1 point;
- distinct micrograph and incomplete line—0 point.

Statistical processing of the results was based on a three-factor analysis of variance (F-criterion), taking into account the influence of the factors "age", "demographic data" and "gender". The level of significance of the differences was determined by student's t-test.

Target group: 365 children from Bulgaria (with Bulgarian mother tongue) with neurotypical development from preschool age participated in the study. The children are divided into groups according to the factors of age, demographic conditions (type of settlement) and gender.

The age distribution includes three subgroups: 4-year-old (116 children—57 girls and 59 boys; average age 4.5 years); 5-year-old (128 children—58 girls and 70 boys; average age 5.6 years); 6-year-old (121 children—58 girls and 63 boys; mean age 6.6 years). The demographic distribution is also in three subgroups: from the capital (195 children), from a large city (90 children), from a small town (80 children). The gender ratio is practically even, with a slight predominance of boys.

All children participating in the study were selected randomly and after informed consent of their parents. Since the purpose of the study is to follow the dynamics of graphomotor skills among children with typical development, those with data on developmental deviations were not included.

3. Results and Discussion

Analysis of variance revealed a statistically significant influence of all three factors—"age", "demographics" and "gender"—on children's graphomotor skills. A positive correlation was also found between the factors "age" and "demography (settlement)", which speaks in favor of the second hypothesis of the study (**Table 1**).

In addition to the main effect of the influence of the age factor, Duncan's test was used to test the significance of the differences in the mean scores of each two groups (**Table 2**). The presence of statistically significant differences between any two means is objective evidence of the positive dynamics of the processes of learning serially organized graphic patterns in the age period of 4 - 6 years. The analysis of the results leads to conclusions regarding the progressive maturation of premotor brain regions of the left hemisphere responsible for programming and functions and kinetic organization of complex movements (manual and articulatory).

As can be seen from the graph, the factor "age" has the greatest influence ($p <$ 0.000, F = 48.143), and its profile is associated with a progressive increase in graphical skills with age (**Figure 2**).

This confirms the hypothesis of the significant influence of the age factor on the development of cerebral mechanisms and on the dynamics of graphomotor functions during the preschool period.

Also of interest is the influence on graphomotor skills of children's social conditions of development related to the factor "type of settlement". The significant

Table 1. Table of variance according to the "Fence" test.

Test "Fence" Rating					
	SS	Degr. of Freedom	MS	F	*p*
Intercept	23560.37	1	23560.37	3007.308	0.000000
Age	754.35	2	377.17	**48.143**	**0.000000**
Place of residence	107.31	2	53.66	**6.849**	**0.001211**
Gender	32.96	1	32.96	**4.207**	**0.041004**
Age * Place of residence	151.47	4	37.87	**4.834**	**0.000835**
Age * Gender	1.96	2	0.98	0.125	0.882611
Place of residence * Gender	1.88	2	0.94	0.120	0.886800
Age * Place of residence * Gender	40.08	4	10.02	1.279	0.277865
Error	2710.69	346	7.83		

Table 2. The significance of the differences in the mean scores of the age groups on the graphic test "Fence".

	Age	{1} – 6.4087	{2} – 8.7717	{3} – 10.918
1	4 years old		0.000009	0.000011
2	5 years old	0.000009		0.000009
3	6 years old	0.000011	0.000009	

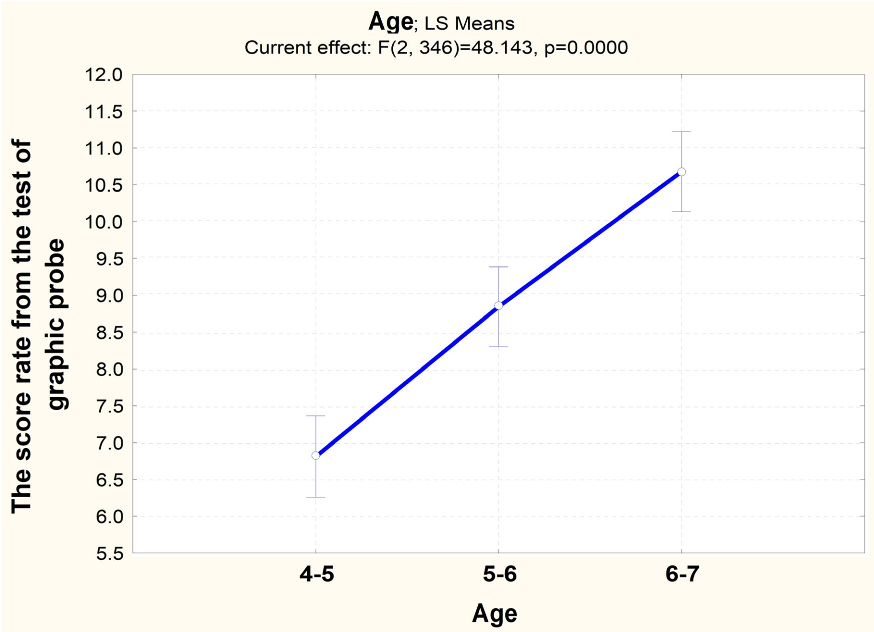

Figure 2. The influence of the factor "age" on the graphic motor skills in children of different ages.

impact of this factor ($p < 0.001$, F = 6.849) is due to the high scores of children living in a medium-sized city (**Figure 3**), which is at odds with our prior expectations of better performance of children from the capital city. Duncan's test analysis showed the following results for the development of graphomotor functions according to the type of settlement: the presence of statistically significant differences between children from the capital and a large city and between children from a large city and a small city; no significant differences between the scores of children in the capital and children from a small city (**Table 3**).

Although to a lesser extent, gender also had a significant effect on the development of children's serial organization of movements and programming functions ($p < 0.04$, providing F = 4.207), associated with higher scores for girls. This fact supports the assertion of a more rapid development in girls of the neural organization of the premotor and prefrontal cortical areas and their associated programming and executive functions. The analysis of the influence of the three independent factors on children's graphomotor functions shows the leading importance of the age factor for their development, which confirms the first hypothesis. This is explained by the natural reflection of morphofunctional ontogenesis on the state and dynamics of mental functions. Therefore, the degree of their development is an objective criterion of brain maturation processes.

Against this background, the data on the reliability of the differences between the three age groups of children in the different settlements are of interest. Differences in graphomotor skills between 4- 5- and 6-year-old children from a small town were the least reliable, followed by differences of the three age groups in a big city and a metropolitan area, where the degree of reliability between the groups was greatest. It can be assumed that the differences in the performance of

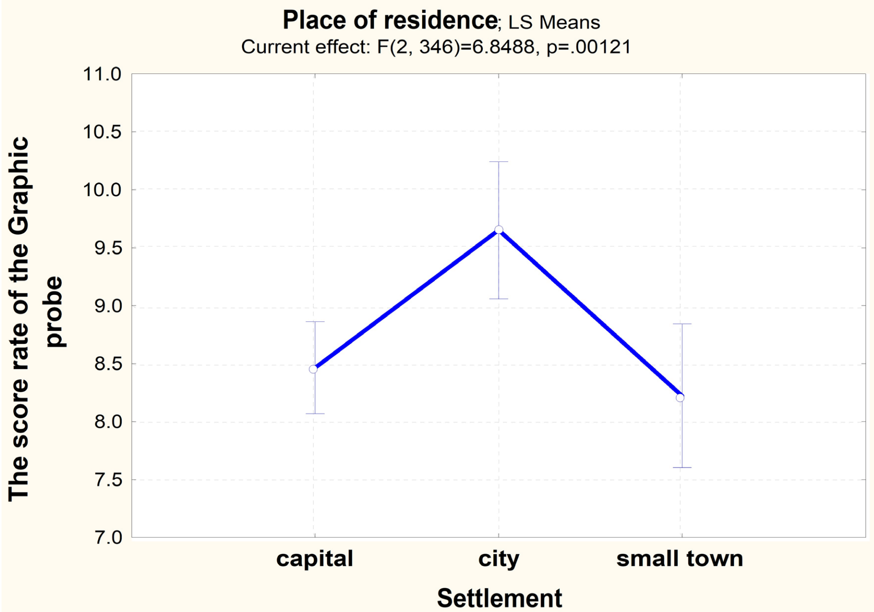

Figure 3. Influence of the factor "type of settlement" on children's graphic motor skills in the period 4 - 6 years of age.

Table 3. Significance of the differences in the average scores of the groups of children from different settlements according to the "Fence" graphic test.

	Type of settlement	{1} – 8.5361	{2} – 9.6222	{3} – 8.2625
1	Capital		0.005093	0.480307
2	Big city	0.005093		0.000662
3	Small town	0.480307	0.000662	

the graphical sample prove the heterochronic nature of the development of the studied functions in children in the mentioned period.

From the point of view of this thesis, it is interesting to see the data obtained on the reliability of the differences between the three age groups of children in the different settlements. Differences in graphomotor skills between 4- 5- and 6-year-old children from a small town were the least reliable, followed by differences of the three age groups in a big city and a metropolitan area, where the degree of reliability between the groups was greatest, i.e., the dynamics of brain function organization were most pronounced. This confirms the assumption of a differential influence of social conditions on the maturation of brain functions, a fact that needs further research.

In general, the data obtained prove the thesis of a heterochronic character of neurobiological and neuropsychological development in the period of 4 - 6 years, sensitive to graphomotor and executive functions of children.

Therefore, like any functional system, that of executive functions goes through a number of critical periods associated with qualitative changes in its organization. Neurophysiological studies (Matchinskaia et al., 1997) report significant changes in the bioelectric brain activity of children in the period 5 - 8 years. The authors relate this fact to the functional maturity of the frontal-thalamic regulatory system, which provides descending impulses from the frontal cortex to other cortical and subcortical areas.

For the purposes of qualitative analysis, the results were processed according to the index of serial organization, which gives objective information about the child's ability to learn and execute a graphic motor program. The quality of the serial performance is evaluated according to the following parameters:

- normal performance;
- drawing elements of different sizes (compensatory execution);
- incorrect execution (slanted vertical lines, bent corners, etc.);
- separate drawing of each element with raising of the hand (pauses and non-smooth execution of the program);
- change of the engine program (expansion by adding redundant elements);
- inert repetition (perseveration) of an extended or simplified program.

Typical examples of the flaws in the kinetic organization of graphic movements are drawing elements of different sizes (height or width), replacing vertical lines with slanted or curved ones, and drawing each element in isolation after a pause. The most serious errors that speak of inability to learn the program and lack of executive control are associated with changing the source program—not observing the order of the elements and drawing only one element (usually the one with a sharp tip). In some cases, children simply draw a straight line to the end of the row.

A particularly typical picture of performance is observed in children of 4 years, when graphic skills are in the early stage of formation and mastering the motor program is very difficult or impossible. The reason for this is the morphofunctional immaturity of the premotor and frontoparietal cortical departments and the weak connections between them. In this age group, the "worst" variants of graphic task performance are observed, with 57% of cases showing inert repetition of a simplified program: drawing only one element (usually the sharp element of the model) or drawing a straight line to the end (**Table 4**).

Therefore, typically developing 4-year-olds can handle simplified versions of single-element motor graphing programs, which should be considered the norm at this age. Connected (fused) drawing is also proving difficult and is being replaced by element-by-element drawing. The latter feature indicates an underdeveloped kinetic organization of graphic activity. **Figures 4-6** present sample individual versions of 4 year olds' performance on the graphical test.

Table 4. The quantitative distribution of the performance criteria of the graphic motor test by age groups.

Age group	normal performance	compensatory drawing	incorrect performance	drawing element by element	superfluous elements	inert repetitions/ perseverations
4 years	1%	4%	9%	9%	20%	57%
5 years	8%	14%	14%	11%	24%	29%
6 years	18%	25%	22%	13%	15%	7%

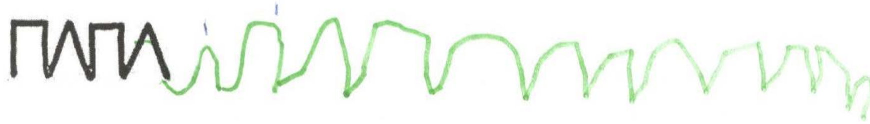

Figure 4. Example of good performance of the graphic program in a child of 4-year-old child.

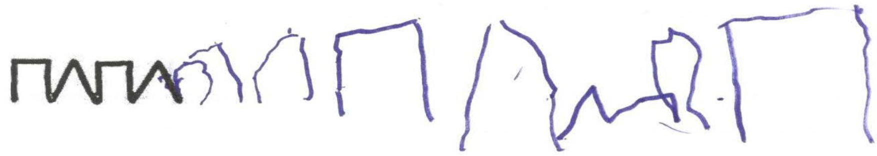

Figure 5. Example of drawing by elements in a child of 4-year-old child.

Figure 6. Example of an impossible graphic sample performed by a 4-year-old child.

The results in 5-year-old children support the conclusion of positive age dynamics of graphomotor functions. The group was characterized by a wide variety of variants of drawing the graphic model, with only 8% of the children achieving the maximum number of performance points. Cases of inert repetition of one element (29%) and addition of redundant elements (24%) predominate (Table 4). Since the percentage difference between the two variants of performance is relatively small, they can be taken as normal for the age of 5 years.

We present exemplary performances of the graphic model by 5-year-old children (Figures 7-9).

The percentage difference between the two methods of performance is relatively small, they can be taken as normal for the age of 5 years. It is important to emphasize that in 5-year-old children, the cases of inert performance decrease almost twice compared to 4-year-old—from 57% to 29% and speak of a significant progress of graphomotor functions. This is a reason to consider the age of 5 years as key for the maturation of brain functional systems responsible for the kinetic organization of movements, executive and spatial functions. We also believe that this proportion of children who demonstrate better visual-motor coordination and program acquisition capabilities will show high school readiness in the future.

The trends in the dynamics of the influence of the age factor on the development of children's graphomotor skills are presented in Table 4.

The presence of reliable differences between the scores of children aged 6 and 5, and children aged 6 and 4, indicates a significantly increased ability to perform the graphic program correctly at the end of the preschool period. The evidence of reliable differences on the indicator of drawing different sized items between 5- and 6-year-old suggests that 5-year-old often use compensatory techniques when reproducing the graphic pattern.

Figure 7. An example of the correct execution of the graphic program by a 5-year-old child.

Figure 8. An example of a change (adding redundant elements with signs of macrography) of the graphic program in a 5-year-old child.

Figure 9. An example of inert repetition of one element in a 5-year-old child.

For a large proportion of 4-year-olds, there is a very low level of graphic skills and an inability to master the motor program, as evidenced by the reliable differences with 5-year-old's scores, especially on the inert performance indicator. Therefore, the graphic task has objective diagnostic value within the neuropsychological study of children who have reached the age of 5 years.

In the 6-year-old age group, only 18% of children learn and execute the motor program correctly. Cases of compensatory implementation of the program predominate (25%). They are explained by limited possibilities for automating movements, which lead to drawing elements of different sizes and spatial arrangement (**Table 4**). Next in frequency are the cases of distortion of the program (inaccurate execution)—22%, when the child distorts the lines and angles when drawing. Continuing deficits in the serial organization of movements and executive functions in 6-year-old children are also confirmed by the cases of expanding the motor program (15%) by adding redundant elements (lower horizontal line between the two parts of the series), as well as by cases of inert repetition (perseverations) of a simplified program (7%). It should be assumed that children making the latter two types of errors when performing the graphics task would fall into the "risk group" of students for learning difficulties.

The figures below present the different ways of performing the graphic sample by the 6-year-old children (**Figures 10-12**).

Polonskaya (2007) used the graphic test to study a large group of typically developing 1st grade students. The results she reports show 30% correct completion of the task, 30% cases of compensatory drawing (drawing different-sized elements), and 30% cases of program expansion (adding elements). The author emphasizes the connection between the level of graphic skills and the school performance of children. According to her, the formation of the serial organization

Figure 10. An example of the correct execution of the graphic program in a 6-year-old child.

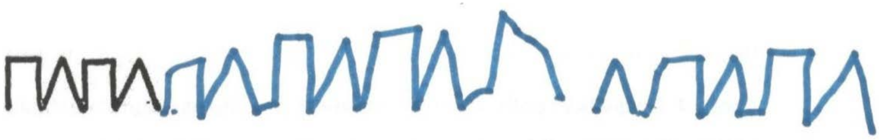

Figure 11. An example of program distortion in a 6-year-old child.

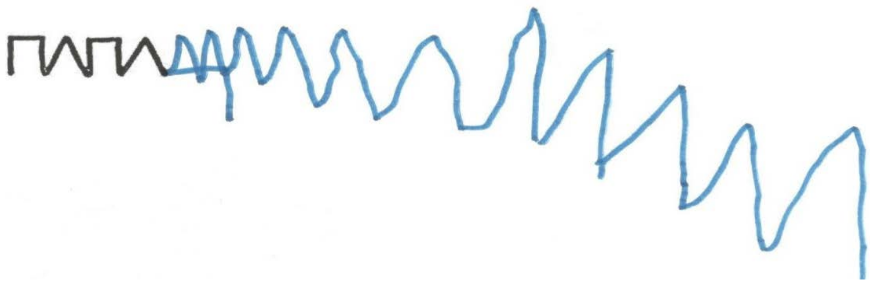

Figure 12. Example of inert repetition of an element of the program with signs of macrography and going out of line in a 6-year-old child.

of movements is an important component in the general psychic development of the child, in particular that of the written and oral forms of speech.

This is also confirmed by the data cited above (Kuzeva, 2017) about deficits in the serial organization of movements and executive functions in students with dyslexia in the process of performing the commented graphic task.

The data on the age distribution of the parameters from the performance of the graphics task in our study were further subjected to analysis with the Student's T-test for the reliability of differences between any two age groups (**Table 5**).

The data in the table show which of the criteria there are significant differences between any two age groups. The most significant differences between each of the groups were observed on the indicator of inert drawing (perseveration) of one element of the program. Similarly, significant differences between two of the groups were also registered on the indicators of normal and compensatory performance of the graphic task. Only between the youngest and the oldest children, reliable differences are also found on the indicator of inaccurate drawing of the elements by size.

On the other hand, the data showed no differences between any two age groups on measures of drawing by elements and adding redundant elements (program expansion). This means that graphomotor functions do not reach a sufficient level at the end of the preschool period, but continue to actively develop during the first years of schooling, which was also confirmed by the authors cited above (Polonskaya, 2007; Kuzeva, 2017).

Table 5. Age comparison for the reliability of the differences in the individual parameters for the performance of the graphic test "Fence".

Age group	normal performance	compensatory drawing	incorrect performance	drawing element by element	superfluous elements	inert repetitions
5 and 4 years old	$p \le 0.05$	$p \le 0.05$	$p \ge 0.05$	$p \ge 0.05$	$p \ge 0.05$	$p \le 0.001$
6 and 4 years old	$p \le 0.001$	$p \le 0.001$	$p \le 0.01$	$p \ge 0.05$	$p \ge 0.05$	$p \le 0.000$
6 and 5 years old	$p \le 0.05$	$p \le 0.05$	$p \ge 0.05$	$p \ge 0.05$	$p \ge 0.05$	$p \le 0.001$

Table 6 presents a qualitative analysis of the influence of demographic factor (settlement type) on graphing task performance for 6-year-old children only, given the predictive value of graphing skills as a predictor of future learning difficulties. The data on the influence of social factors show an interesting distribution of children's scores across the three types of locality—capital city, big city and small town, presented in Figure 3. The highest level of development of graphomotor functions is recorded in children from the large city, followed by children in the capital city and children in the small city.

In the big city, the prevalence of correct completion of the graphic task (30%) was 15% and 11%, respectively, while in the capital and small town. In the capital city, the cases of incorrect execution (slanted vertical lines, bent corners) predominate, while in the small town drawing by elements predominates in the execution of the task. The high frequency of cases of changes in the motor program and of inert repetition (perseveration) of an element in children from the small town is evidence of a greater risk of future development of learning difficulties.

On the basis of the individual results of all the children studied, an attempt was made to establish approximate age norms for the performance of the graphic test. For this purpose, the frequency distribution of children's scores across ages was subjected to statistical processing. Depending on the degree of performance on the graphical task and the scores obtained, three normative subgroups were distinguished within each age group, designated as "low norm", "typical norm" and "high norm" (Table 7).

The formation of the three normative subgroups across ages shows an interesting trend in the distribution of raw scores. The range of scores in the low norm subgroup for 4- and 5-year-old is smaller (the lower quartile for 4-year-old is 5 and for 5-year-old it is 7). In children aged 6 years, the subgroup of the low norm is in wider limits (lower quartile is 10). The low norm subgroup included similar numbers of children of each age: 45 children at 4 years (39%), 46 children at 5 years (36%), and 45 children at 6 years (37%).

An opposite trend was observed in the ranges of point scores in the high norm group—they were wider in the 4- and 5-year-old (respectively, 4 points for the first and 3 points for the second group) and very narrow in the 6-year-old (1 point). The quantitative distribution of children in this subgroup is: 34 children at 4 years (30%), 41 children at 5 years (32%) and 35 children at 6 years (30%).

Table 6. The quantitative distribution of the performance criteria of the graphic motor test of children from different settlements.

Groups by type of settlement	normal implementation	compensatory drawing	incorrect execution	drawing element by element	superfluous elements	inert repetitions
Capital	15%	32%	**35%**	0%	14%	4%
Big city	**30%**	23%	7%	23%	14%	3%
Small town	11%	8%	8%	**35%**	19%	19%

Table 7. Age indicators for the normative distribution of the performance of the graphomotor test.

Age group	Groups of normative distribution (point results)		
	low norm	*typical norm*	*high norm*
4-year-old children	0 - 5 points	6 - 8 points	9 - 13 points
5-year-old children	0 - 7 points	8 - 10 points	11 - 14 points
6-year-old children	0 - 10 points	11 - 12 points	13 - 14 points

Characteristic of the subgroup of the typical norm is that the range of point results in all ages is narrowed to 2 points, and the number of children shows a slight increase with age: 36 children at 4 years (31%), 40 children at 5 years (32%) and 42 children aged 6 years (34%).

The distribution of normative groups for children aged 6 who are about to study at school deserves special attention. The wider range of scores in the low-norm subgroup indicates internal heterogeneity and greater individual differences in children's degree of graphomotor skills. In general, the underdevelopment of graphic habits in the period of 6 years is an indicator of delayed formation of fronto-temporal neural connections and executive functions. This is a reason to assume that children assigned to the subgroup "low norm" will with a high probability demonstrate specific difficulties in the process of school education.

The presented data allow to draw a conclusion about the presence of both regular and general trends and significant differences in the development of serial graphic skills of children of the same age in the period 4 - 6 years. This proves the thesis of a great diversity in the dynamics of maturation of higher mental functions within the typical child population, based on the complex interaction of biological and social factors.

The variability in graphic test performance scores in the 4 - 6 years period confirms the principle of heterochrony in the development of serial organization of movements and associated spatial and executive functions. Pronounced individual differences between children of the same age in the rates of maturation of the functional graphomotor system and the brain regions involved, confirms the need for increased development of the neuropsychology of individual differences as a basis for the development of age norms to facilitate differential diagnosis and prognosis in various forms of developmental deviations.

4. Summary

The observed individual, sociocultural and age differences in the implementation of the neuropsychological graphic test "Fence" conclusively prove the action of the heterochronic principle of development, which has a leading importance for child neuropsychology in the analysis of the mechanisms and dynamics of higher mental functions. The period between 4 and 6 years is sensitive in terms of the morphological and functional maturity of the frontal (premotor and prefrontal) fields and their connections with the parietal lobe of the cortex, responsible for the serial organization of graphic movements and related spatial and executive functions.

Despite the positive dynamics in graphomotor skills during the considered period, their improvement and reaching an optimal level occurs at an early school age. In this regard, deficits in various aspects of graphic motor development and executive functions in 6-year-old children can be interpreted as early prognostic markers and predisposing factors for the emergence of dyslexic symptoms in the learning process. The diagnostic efforts of children's neuropsychology should be maximally oriented towards the end of the preschool period, as a time of active formation of the neurophysiological prerequisites for children's school readiness.

The results of the research provide a basis for formulating some recommendations for the psychological-pedagogical practice in the preschool age period:

- mandatory diagnosis of the graphomotor condition of children after 5 years of age;
- purposeful formation of graphic skills through tasks for redrawing figures and tasks for mastering a motor graphics program;
- stimulation of visual-motor coordination and spatial orientation through tasks for drawing objects by pattern and memory, connecting differently located figures, writing and connecting elements of letters in a limited space, etc.

Directions for future research:

- longitudinal monitoring of the dynamics of graphomotor functions in children at the end of preschool and the beginning of the school period;
- comparative analysis of the state of graphomotor skills in students with and without writing disorders.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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