Chapter

Dynamics of Praxis Functions in the Context of Maturation of the Parietal and Frontal Brain Regions in the Period 4-6 Years of Age

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Abstract

In recent years, child neuropsychology has paid special attention to ontogenesis and trends in the development of practical functions during the preschool period, given their relationship to practical skills and children's readiness to learn. On the other hand, the dynamics of complex types of praxis is an indicator of the integration between the brain regions responsible for the perception, programming and recoding of motor patterns. The article presents a comparative analysis of data from a study of two types of praxis functions (dynamic praxis and spatial postural praxis) in children with typical development in the period 4–6 years. The specificity of the performance of neuropsychological tests is an indicator of the functioning and the degree of neuronal connectivity of the parietal and premotor regions of the left hemisphere. The data from the study show a similar trend in the dynamics of the studied functions and the influence on them of three independent factors: age, social conditions (type of settlement) and gender. Significant improvement in the performance of the tasks is observed in children at the age of 6, which is a reason to consider this age as critical for the maturation and neurophysiological connectivity of the structures of the parietal and premotor regions. The assessment of complex types of praxis in this period is an objective indicator of the neuropsychological development of children and has an indisputable prognostic effect for future learning disorders.

Keywords: child neuropsychology, dynamic praxis, spatial postural praxis, children with typical development, parietal and premotor regions, neuropsychological development, learning disorders

1. Introduction

In recent years, the attention of specialists is increasingly focused on the assessment of motor functions in the preschool period. One of the reasons is the growing number of children with delayed motor development, whose symptoms can be either leading (Developmental dyspraxia, Developmental Coordination Disorder) or part of other neurodevelopmental syndromes (Autism Spectrum Disorders, Developmental Dyslexia and Attention Deficit Hyperactivity Disorder). In any case, the incomplete formation of motor skills is accompanied by cognitive, language, and emotional disorders that have a negative impact on children's school readiness.

The objective analysis of the observed deficits is directly related to the differential diagnostic and prognostic aspects of child development. The latter are the subject of child neuropsychology, whose methodological tools are aimed at analyzing the formation of higher mental functions (gnosis, praxis and language) and their relationship with the maturation of different brain regions. The complex neurophysiological organization of these functions and the individual rates of development of the child's brain are a prerequisite for separating the neuropsychology of individual differences (differential neuropsychology). Developments in the field outline the natural stages and patterns of formation of higher mental functions, their sensitive periods and age norms.

The range of age norms, which determines the registration of developmental disorders, is related to the tendency to "go" beyond the traditional framework of pathology and draws attention to the stages and patterns of typical ontogenesis. The diagnosis of any mental function is based on the notions of its normative meanings and is important for identifying so-called "soft" developmental abnormalities [1]. Along with the general characteristics of the functions, the researchers' interest is focused on the variability and peculiarities of neuropsychological development, referred to as the "typology of the norm". This explains the increasing emphasis on the cases of the "low" child norm, defined as a risk for the development of specific learning difficulties [2].

The active inclusion of neuropsychological methods in the study of the child population is associated with new trends in the analysis of mental development - from purely diagnostic to prognostic; from finding isolated deficits to describing syndromes and developing adequate treatment strategies [3]. The changes also reflect the idea of replacing the static approach with a dynamic one, in which the analysis focuses on the interaction between brain structures and mental functioning in the context of social conditions [4].

Chronology and normative diversity in the development of praxis functions are one of the least developed units in child neuropsychology. These functions have a complex brain organization, including processes of spatial orientation, coordination, programming and recoding of motor models, which is why their assessment has important prognostic value for child development. The fact is that, unlike established tools for language and cognitive functions, the diagnosis of motor development has not yet developed a gold standard assessment tool [5]. One of the explanations is that the early developments on the problems of motor development are mainly in the field of psychology and refer to the first half of the 20th century. By the 1960s, the subject of research has shifted from the biology of children's motor behavior in the direction of language and cognitive development as genetically related to learning [6].

Scientific developments in recent decades are an example of compensating for this discrepancy and show increased interest in the laws of motor ontogenesis and its neurophysiological organization. This is largely due to the recognition that the level of motor development is a determining factor for growth and behavior [7]. This is a reason to assume that the identification of deficits in complex motor (practical) functions during the preschool period allows timely support and optimization of cognitive and emotional-behavioral development of children.

2. Brain organization of motor development

2.1 Conceptual foundations of development

Gabbard and co-authors [7] consider motor development as a change in motor behavior influenced by the interaction of biological factors and the influence of the environment (training and education). Discussions on the subject correspond to the theory of dynamic systems, according to which man is a dynamic and self-organizing unit, consisting of a large number of systems (nervous, muscular, cognitive, etc.), each of which has different levels of organization. From this position, development is seen as a process of constant change in behavioral patterns under the influence of the environment and tasks. The theory outlines three main variables - individual, task and environment, the interaction between which generates spontaneous adaptive behavior. According to the cited authors, dynamic systems should be considered as part of the global (general) development systems, which approach gives a broader perspective in the study and understanding of development. Attempts are also made to integrate the theory of dynamic systems in the process of motor therapy in some forms of pathology - Autism Spectrum Disorders, Developmental Coordination Disorder, post-stroke conditions [6].

By accepting the stimulating role of the environment as leading to development, the theory of dynamic systems differs significantly from the older neuronal theory of maturation, which emphasizes the role of the nervous system [8]. According to the neuronal maturation theory, the stimulating effect of the environment is limited by the genetically set stages of maturation of the nervous system. From this point of view, training and therapy can lead to changes in the development of a function only after the associated nerve structures reach a certain degree of maturity.

A compromise between the first two is the Neuronal Group Selection Theory, which views development as the result of a complex intertwining of information from genes and environment. It defines variability as a basic principle of typical ontogenesis, relating to all its parameters - duration of stages of development, motor, language and cognitive skills. Neuronal Group Selection Theory postulates the initial existence of complex vertical connections between a huge number of neurons at the cortical and subcortical level, united in dynamically changing network systems (neuronal groups) with the character of functional units. The structural and functional organization of neuronal groups varies and is selected depending on the stage of development, afferent information and behavioral requirements (in [8]).

Similar ideas are shared by the theory of neural modular organization of the central nervous system [9, 10], which considers the structural development of the cortex as related to the formation of neural ensembles (neural centers) underlying mental ontogenesis. Those of them, which have the same type of functions, are provided in a larger structure - modules, with the nature of the basic units for information processing. Neural ensembles in all parts of the cortex are in a process of constant change. Although they obey a single mechanism, they have uneven dynamics over time. The rate of brain transformation is heterochronous, and developmental changes are faster the smaller the child.

The last two theories correspond closely with the leading principle in child neuropsychology for heterochronous formation of higher mental functions [11–13]. According to him, the functional organization of mental development is subject to a certain chronological sequence, in which each function is distinguished by its chronological formula and cycle of development, specifically related to the stimuli of the environment. The uneven formation of the functions explains the differences in their sensitive periods and the anticipatory development of some of them. The combination of genetically determined heterochrony and environmental influences determine the variety of individual (phenotypic) variants of development, often located at both extremes of the age norm - high and low [14]. Phenotypic diversity is among the leading goals of differential neuropsychology, related to the analysis of variants in the formation of cortical–subcortical brain systems and partial retardation in the development of individual higher functions (gnostic, practical, linguistic) within the typical development [11].

The syndrome analysis has a direct connection with the regularities in the development, the main task of which is the assessment of the individual neuropsychic profile. Except in cases of neurodevelopmental disorders, it also applies to the variety of cases within the typical child development. In this regard, some authors [13] use the term "positive developmental syndrome" as a combination of functions that have reached a certain level of development (positive symptoms). Due to the rapid changes in cerebral functional systems in early childhood, the derivation of regulatory trends should cover close age periods.

At the same time, the objective assessment of each individual case requires consideration of the dynamics of developmental changes related to the analysis of the beginning and direction of the developmental trajectory of the specific phenotype [15]. It should be taken into account that the initial phase of brain development is very different from the final one [16–18]. The reason is that in the beginning the normal children's cortex is strongly interconnected and the functioning modules are not independent, which explains the cascading effects of any early impairment on the formation and dynamics of new habits [16]. Its transformation into more and more specialized and localized as functions takes place gradually and under the influence of the constantly incoming information.

2.2 Neurophysiological organization of complex motor (praxis) functions

The ontogenesis of motor functions has a very early onset in childhood development. Like other higher functions, they depend on the dynamics of the physiological maturation of the brain in its three dimensions: vertical, horizontal and lateral, subject to the principles of heterochrony and systemicity. According to morphological studies, in the first years of postnatal ontogenesis the system of vertical connections (crust - subcortex) develops most actively, and the period of 5–6 years is a time of intensive formation of horizontal connections (intrahemispheric and interhemispheric). The levels of the projection and associative zones of the cortex also reach maturity at different time periods [19].

The formation of practical functions is determined by the stages and dynamics of motor development and its main components such as accuracy, speed and coordination. Like other higher cortical functions, they have a complex brain organization based on neural networks between a large number of sensory and motor regions of the cortex and subcortex. Despite the variety of forms, each type of praxis presupposes the execution of purposeful and consciously controlled movements with the character of automatisms. Their development at an early age is a condition for the acquisition of social habits and school skills (in particular, graphomotor). The importance of visual-motor integration and fine motor control for the formation of skills and quality of writing has been proven [5, 20, 21]. There is a large amount of evidence for the importance of visual-motor integration and fine motor control in the formation of skills and quality of writing [5, 20, 21]. Leading role in the formation of complex coordinated movements has different structures of the frontal and parietal lobes. Their maximum connectivity is the basis for the acquisition and implementation of motor habits [22].

Compared to other organs, the brain reaches adult size at a much earlier stage. Compared to other organs, the brain reaches adult size at a much earlier stage. The maturation of the cortical areas regulates the sequence and stages of development of the mental functions and abilities associated with these areas. For example, between 3 and 12 months, the increasing number of synapses in the auditory and visual cortex corresponds to the accelerated development of the child's auditory and visual perceptions. Apart from being a sensitive period for the sensory base of mental functions, the first year is associated with the active development of the motor (precentral) and kinesthetic (postcentral) areas of the cortex [23, 24].

The maturation of the leading structures for the motor functions of the frontal lobe (motor, premotor and prefrontal areas) is subject to the principle of heterochronous development. Data from neurophysiological studies show that in the first two years of life the motor areas develop most actively, and in the period 2–4 years their neuronal organization approaches that of adults. Structurally and functionally, the premotor area is close to the mature brain at 7 years of age. In the slowest maturing prefrontal cortex, several stages of significant changes in the neuronal ensemble organization are observed, which relate to the time 1 year, 3 years, 5–6 years, 9 years, and 12–14 years [25–27]. Although they do not have motor functions, the fields of the prefrontal cortex are crucial for the regulation of motor behavior. This is due to their close connection with the posterior associative cortex, the premotor cortex, the basal ganglia and the cerebellum.

Of the areas of parietal lobe, gyrus angularis and gyrus supramarginalis are those that are crucial for the development of the most complex mental functions. There is evidence for their connection with the integrative function of speech for spatially organized and visually controlled subject actions, as well as for the periods of the most significant morphofunctional changes in these regions. These periods refer to 2 and 7 years of age and coincide with a qualitative complication of the child's activities [10]. Some authors [22] consider the left supramarginal gyrus as a structure directly involved in the formation of praxis, in particular in the acquisition of motor habits, graphomotor and speech skills.

Dowell and co-authors [28] comment on the complex neurophysiological organization of praxis functions and present the structural-functional mechanism associated with the realization of learned movements. It is based on literature data, according to which the mechanism is based on the interaction of the areas of the frontal and parietal lobes. The analysis presents gyrus angularis and gyrus supramarginalis as a place for storage of spatio-temporal notions of learned movements. Due to their close connection with the structures of the premotor cortex, they have a stimulating effect on its programming functions. As a result, the premotor divisions recode the visual motor representations into motor programs and direct them to the motor cortex for execution. This leads to the conclusion that praxis functions have a universal organization, including the following main components: formation of ideas for the somatospatial and temporal characteristics of the movement (parietal cortex) and recoding of the visual image in the motor programs (premotor areas of the frontal cortex).

Because the development of praxis is based on the coding of visually perceived movement with subsequent motor imitation, a number of researchers emphasize its connection with the work of the mirror nervous system. Both forms of imitation - for known and unknown movements are related to the mechanism of comparing the currently perceived motor information with the respective motor representations. Summary data from fMRI study [29, 30] show the importance of the mirror nervous system for the early imitative behavior of children and emphasize the role of "core circuit" for imitation. It is based on the connections between three regions: the superior temporal sulcus (visual description of the action), the parietal parts of the mirror system (motor components of the action) and the frontal parts of the same (purpose of the action). Separate studies [31] have also linked gestural imitation processes to the cortical neural network of the lower frontal, anterior lower parietal and posterior upper temporal lobes, raising the idea of its bilateral organization. The latter is commented by a number of authors [32, 33], according to which, despite its bilateral organization, the imitation of the gesture has a more pronounced lateralization in the area of the left parietal cortex.

The analysis of the literature outlines the period of middle childhood (4–6 years) as sensitive to neuropsychological development. Peculiarities of motor functioning in children with typical development have important diagnostic and prognostic significance for learning readiness. However, the assessment of praxis functions during this period remains poorly developed within child neuropsychology. Systematic research in this direction faces the following tasks: outlining age trends and deriving standards for the development of praxis; development of differential diagnostic criteria for assessment of children at risk of learning disabilities; formulation of methods and approaches for preventive therapy in case of delayed formation of praxis functions. Some of these tasks we try to solve in the presented analysis of our own research.

3. Description of the research

3.1 Research objectives

The main goal of the study is to analyze the state of two types of praxis with similar brain mechanisms - dynamic and spatial postural praxis in children of preschool age (4–6 years) with typical development. The additional comparative analysis of the results aims to outline the state of the fronto-parietal neural connectivity and the developmental tendencies of the complex practical functions in the indicated age period.

3.2 Research methods

Two neuropsychological samples adapted for childhood were used to study the praxis functions - a sample for dynamic praxis and a sample for spatial postural praxis. The samples are included in the Neuropsychological Diagnostic Battery for Children [34] and are described below.

3.2.1 Test for dynamic (kinetic) praxis

It is from the group of samples for serial (successive) organization of movements. The application of the sample allows studying the following praxis components: mastering of a motor program according to a sample and automation of the program (model) with switching of the movements. Given the early age of the children, the sample includes two consecutive programs with increasing difficulty: the first alternates two elements (fist - "side"), and the second alternating elements are three (fist - "side" - palm). The movements are demonstrated by the researcher three times at a moderate pace. The instruction requires the child to memorize and repeat them six times as quickly as possible. In case of incorrect implementation, three levels of assistance are offered: first degree - re-demonstration; second degree - simultaneous performance (together with the child); third degree - simultaneous performance with verbal comment (naming the movements).

The evaluation of the performance of the two series is similar and is based on the following criteria:

- After the first demonstration - 4 points;
- After first aid (re-demonstration) - 3 points;
- After the second level of assistance (joint implementation) - 2 points;
- After the third degree of assistance (with verbal comment) - 1 point;
- Failure and after all levels of assistance - 0 points.

The analysis of the mechanisms of the dynamic praxis sample outlines its complex nature, based on the involvement of different cortical areas. Performance depends on both the development of executive functions and the acquisition of consciously controlled movements (frontal cortex) and the ability to mimic movements (lower frontal, anterior lower parietal and upper temporal lobes), deficits in which are the leading symptom in cases of developmental dyspraxia [31, 32]. Experimental data show qualitative changes in executive functions during preschool and early school age, associated with progressive growth of posterior and anterior associative fields and increased density of neural groups in the regions of the forehead [35, 36]. This defines the study of dynamic praxis as a way to assess the condition and development of the fronto-parietal nerve connections. At the same time, the heterochronous nature of neuropsychic ontogenesis hypothesizes differences in the ability to learn motor programs among typically developing children. This has great prognostic value, as it allows separating the cases of low normative performances related to the risk of learning difficulties.

3.2.2 Spatial postural praxis sample (head test)

The sample was proposed by H. Head in the early 20th century to evaluate ideomotor practice for new movements in cases of local brain damage. The variant we use was modified by Luria and defined by him as a "spatial practice of posture." Like the first, the Head test is also complex. What is specific about it is a more pronounced emphasis on the visual–spatial organization of the movements of the hand in the coordinate space of the face (horizontal, frontal, sagittal). The defining role in its implementation is played by the ideas about one's own body (body scheme) and the processes of spatial synthesis (spatial recoding), directly related to the work of the lower parietal areas. At the same time, the gestural-imitative nature of the tasks connects its neurophysiological mechanisms with bilateral fronto-parietal activity, more pronounced in the area of the left parietal cortex [28, 31].

In order to evaluate as objectively as possible, we used the sensitized version of the sample. In it, the researcher sits opposite the child and demonstrates different poses with both hands. The child should repeat them, focusing on the parts of his own body. The instruction pays special attention to the requirement that what the adult does with his right or left hand, the child must do with his right or left hand. Before the beginning of the demonstration, the child's right and left orientation on his own body and on the person sitting opposite is checked.

The demonstrated movements are divided into two groups on the principle of increasing difficulty. The first group includes 10 movements with one hand, and the second group includes 3 movements with both hands simultaneously. Bimanual movements are demonstrated only if the child completes the last three tasks of the first part (8, 9 and 10).

First group of movements:

1. The palm of the right hand on the right cheek;

2. The nape of the left hand on the left cheek;

3. The palm of the left hand on the right cheek;

4. Right hand (palm forward) rests right cheek;

5. The dorsal part of the right hand rests the chin (fingers forward);

6. The fingers of the left hand to the chin;

7. Right hand in front of the forehead (palm pointing down);

8. The palm of the left hand in front of the forehead (vertical position, facing to the right);

9. Right hand in a fist under the chin;

10. Left hand in a fist to the left cheek.

The second group of movements:

1. Left hand (palm) on the right cheek, the back of the right hand rests the left elbow;

2. The nape of the left hand is placed on the right, clenched into a fist;

3. The left hand holds the right ear; the back of the right hand is on the left cheek.

In both movements, the initial assessment is formed on the basis of the following criteria:

- Proper performance - 2 points;

- Mirror performance (spatial error type) - 1 point;

- Wrong performance (somatotopic error) - 0 points.

Despite some differences, the imitative nature of the samples for dynamic praxis and spatial postural praxis determines the common elements of their neurophysiological mechanisms. As mentioned, they are related to the formation and dynamics of complexes of the fronto-parietal nerve connections. Both samples involve preserving the spatio-temporal characteristics of visually perceived motor patterns (lower parietal divisions with more pronounced left hemispheric activity), recoding the representational images in appropriate motor programs (premotor divisions of the frontal lobe) and directing them to the motor cortex for execution. The specificity and tendencies of the performance of tasks by typically developing children in preschool age are indirect evidence of the dynamics of maturation of the cerebral mechanisms of complex praxis functions.

3.3 Participants

365 typically developing children without motor impairment signs participated in the study. All children are 4–6 years old, attend state children's schools and have Bulgarian as their mother tongue. The study considers the influence on the development of the praxis functions of three factors - age, demographic conditions (type of settlement) and gender. The following groups were formed in this connection: three age groups: 4-year-olds (116 children), 5-year-olds (128 children) and 6-year-olds (121 children); three demographic groups: - 195 children from the capital (1,500,000 inhabitance), 90 children from the big city (80,000 inhabitance) and 80 children from the small town (11,000 inhabitance). The proportion according to gender is 173 male and 192 female.

3.4 Statistics

The following statistical methods were used to process the results: three-factor analysis of variance for independent variables (F-criterion) and Post-Hoc analysis (Duncan test) to check the differences between the compared averages in the dispersion complex. The use of three-factor analysis of variance is explained by the specifics of the sample of subjects, which requires the separation of 3 independent factors - age, demographic conditions (type of settlement) and gender. For the needs of qualitative interpretation of the data, the analysis was supplemented by the percentage of types of incorrect answers when performing the tasks.

4. Results

The data from the statistical processing of the results will be presented separately for each of the samples.

4.1 Dynamic praxis test

The results of the analysis of variance showed a statistically significant influence on the state of the dynamic (serial) organization of movements and of all three factors. Statistically strongest influence was the factor age ($F = 15.62$; $p < 0.00000$), followed by the influence of the demographic factors ($F = 9.82$; $p < 0.00007$) and gender ($F = 3.89$; $p < 0.0493$). The interaction between age and demographic factors was also statistically significant ($F = 4.033$; $p < 0.003$), as was the triple interaction between age * settlement * gender ($F = 4.91$; $p < 0.00073$).

The profile of the age factor shows a regular increase in the scores of the test in the observed age period. The most significant increase is in the transition from 5 to 6 years; the differences in the average scores of children aged 4 and 5 are insignificant (**Figure 1**).

The data from the statistical check of the influence of the age factor are also confirmed by the Duncan test. It shows significant differences between the results of 6-year-olds and those of the other two age groups (**Table 1**).

The graph outlining the influence of the demographic factor shows the highest average results for children from large cities and much lower ones for children from the capital and small cities (**Figure 2**). The fact is confirmed by Duncan's test, according to which there are significant differences between the average scores in the big city and those in other settlements. There are no significant differences between the average results of the children from the capital and the small town (**Table 2**). This means that the statistically significant influence of the demographic factor is due to the very high results of the children from the big city.

The statistical influence of the gender factor is determined by the significant differences in the average results of boys and girls, where girls show better achievements in learning and performing motor programs (**Figure 3**).

The additional distribution of the results according to the different evaluation criteria outlines the trends in the development of the dynamic praxis in the period 4–6 years and supports the qualitative interpretation of the data (**Table 3**). Note that in all tables the highest values are indicated in bold.

Naturally, the weakest development of dynamic praxis is observed in children at 4 years of age. It is confirmed by the fact of the lowest performance after the first demonstration in both programs. In the two-element program, the highest results of the 4-year-olds (40%) are based on re-demonstration, and the highest in the three-element program (33%) are based on joint implementation. More than half

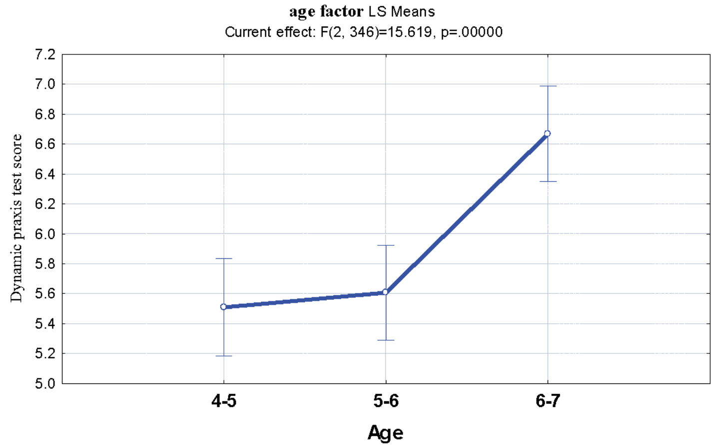

Figure 1.
Effect of age factor on the results of dynamic praxis.

Ages	{1} - 5.3043	{2} - 5.5984	{3} - 6.5574
4 years		0.163378	**0.000011**
5 years	0.163378		**0.000014**
6 years	**0.000011**	**0.000014**	

Table 1.
Significance of differences in the average scores of each age group in the dynamic praxis sample.

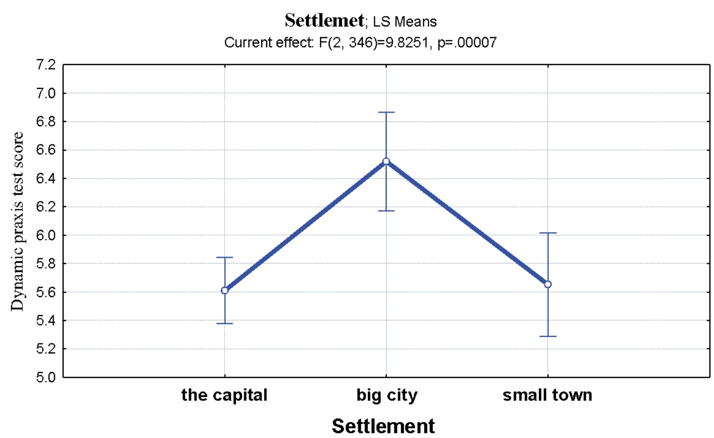

Figure 2.
Effect of demographic factor on the results of dynamic praxis.

Settlement	{1} - 5.6237	{2} - 6.4667	{3} - 5.6000
the capital		**0.000216**	0.916957
big city	**0.000216**		**0.000210**
small town	0.916957	**0.000210**	

Table 2.
Significance of the differences in the average scores between the children from the different settlements on the sample for dynamic praxis.

of the 5-year-old children (56%) master the two-element program after the first demonstration, and here too the largest number (27%) is those who master the three-element program after joint implementation. Confirmation of the positive

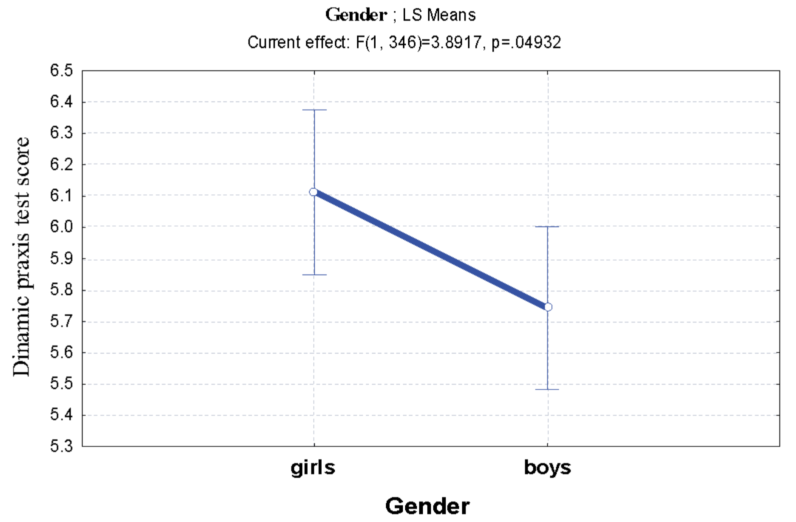

Figure 3.
Effect of gender factor on the results of dynamic praxis.

dynamics of this type of practice in both age groups gives the implementation of the program of three elements after the first demonstration: such is registered in 13% of children at 4 years and in 23% of children at 5 years. For comparison, in the group of 6-year-olds the performance of the sample after the first demonstration was respectively: 76% (in the two-element program) and 36% (in the three-element program).

4.2 Spatial postural praxis sample

In the sample for spatial postural (ideomotor) praxis, the values of the F-criterion show a statistically significant influence of the same factors: age (F = 23.44; p < 0.000), demographic conditions (F = 8.142; p < 0.000) and gender (F = 6640; p < 0.010). The double interaction age * settlement is also significant (F = 6766; p < 0.000). Similar to the previous one, in this sample the profile of the age factor has the greatest influence. It shows a gradual increase in the total score in the period 4–6 years, with a sharp rise in values in 6-year-old children (**Figure 4**).

According to Duncan's test, statistically significant differences are observed between the mean scores of each of the two age groups (**Table 4**).

In both the dynamic praxis test and the ideomotor praxis test, the statistically significant influence of the demographic factor is due to the higher scores of children in the big city, followed by children in the small town and children in the capital (**Figure 5**).

This explains the existence of statistically significant differences between the results of children from the capital and the big city and children from the capital and the small town (**Table 5**). Due to the close results, there are no significant differences between the average scores of children from a big city and a small town.

Similarly to the first sample, the influence of the sex factor turned out to be, which in the sample for spatial postural praxis is again due to the higher average score of the girls (**Figure 6**).

In parallel with the cases of correct performance, in all age groups of children were analyzed the cases of mirror performance (echopraxic) and incorrect performance of the stimuli in the sample (**Table 6**). The following age trend in the distribution of the ways of performing the sample is outlined: in children at the age of 4 the cases of correct, mirror and wrong performance are distributed almost evenly (34% - 36% - 30%), with a slight predominance of the mirror performance; in children aged 5 and 6, the cases of correct implementation prevail against the

	Program of 2 elements				Program of 3 elements				
Ages	**1st demonstration**	**2nd demonstration**	**joint implementation**	**with a verbal comment**	**1st demonstration**	**2nd demonstration**	**joint implementation**	**with a verbal comment**	**wrong execution**
4 years	37%	**40%**	20%	3%	13%	28%	**33%**	23%	3%
5 years	**56%**	24%	12%	9%	23%	22%	**27%**	19%	9%
6 years	**76%**	16%	5%	3%	**36%**	33%	22%	7%	2%

Table 3.
Distribution of the results according to the performance criteria of the dynamic praxis test.

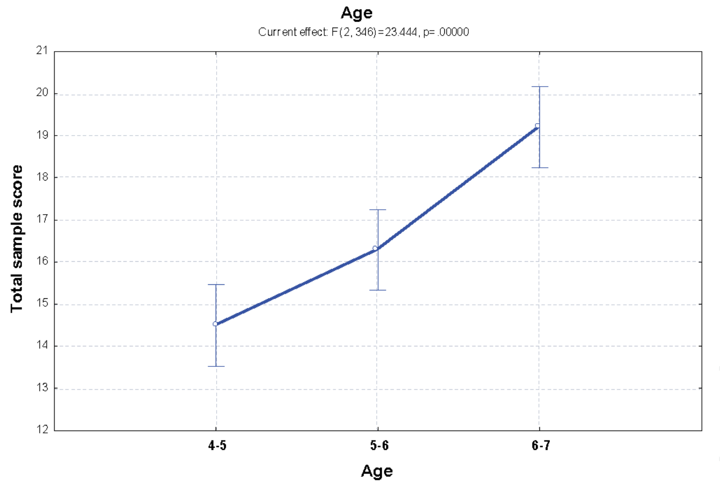

Figure 4.
Effect of age factor on the total score for spatial postural praxis ((ideomotor) praxis).

Age	**{1} - 8.8696**	**{2} - 11.276**	**{3} - 16.000**
4 ages		**0.011307**	**0.000011**
5 ages	**0.011307**		**0.000009**
6 ages	**0.000011**	**0.000009**	

Table 4.
Significance of differences in the average scores of each age group for spatial postural (ideomotor) praxis.

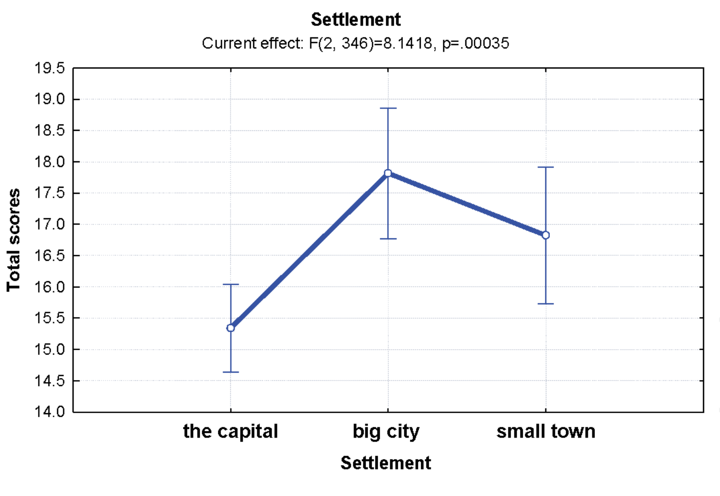

Figure 5.
Effect of the demographic (settlement) factor on the total score for spatial postural praxis (ideomotor) praxis).

Settlement	**{1} - 15.402**	**{2} - 17.700**	**{3} - 16.912**
The capital		**0.001127**	**0.027192**
Big city	**0.001127**		0.249477
Small town	**0.027192**	0.249477	

Table 5.
Significance of differences in the average scores for spatial postural praxis between children from different settlement.

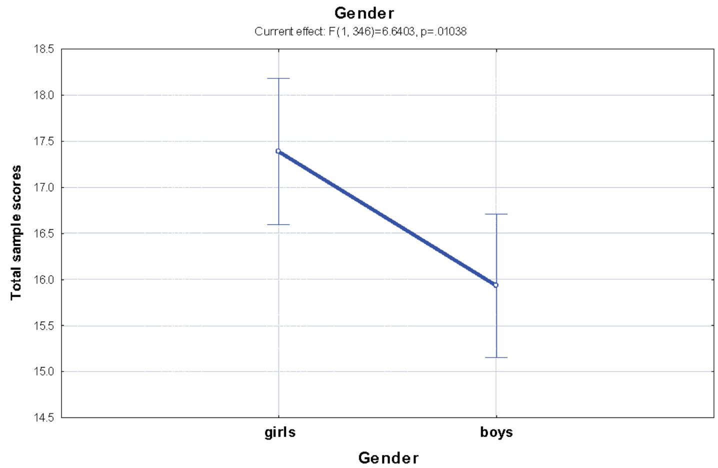

Figure 6.
Effect of the gender factor on the total score for spatial postural praxis (ideomotor) praxis).

Age	Proper performance	Mirror performance	Wrong performance
4 ages	34%	**36%**	30%
5 ages	**44%**	35%	21%
6 ages	**63%**	23%	14%

Table 6.
Distribution of the types of performance of the sample for spatial postural practice in all groups of children.

background of the reduction of the wrong, most typical for 6-year-olds, respectively: the distribution of cases of correct, mirror and wrong performance in children at 5 years is 44% - 35% - 21%, and in children at 6 years it is 63% - 23% - 14%.

5. Comparative data analysis (discussion)

The results of the study of the two types of praxis functions will be commented both sequentially and comparatively. The purpose of such a presentation is to derive the features and general trends in their development.

As mentioned, although they have their own specifics, dynamic and ideomotor practice has a similar neurophysiological organization associated with their imitative nature. Their implementation implies preservation of the spatial and temporal characteristics of the visually perceived movements (lower parts of the parietal lobe), their recoding in motor programs (premotor areas of the frontal lobe) and subsequent reproduction (motor lobes of the frontal lobe).

Statistical analysis of the data from the **dynamic praxis** sample showed a significant influence on the performance of three independent factors: age ($F = 15.62$; $p < 0.00000$), demographic conditions ($F = 9.82$; $p < 0.00007$) and gender ($F = 3.89$; $p < 0.0493$), as well as the interaction of some of them. The age factor has the strongest influence on the performance of the tasks, which is confirmed by the results of the Duncan test (**Table 1**). There were no significant differences between the groups of children aged 4 and 5, which indicates a close level of skills to perform consecutive movements. Significant differences in the results are registered between each of the indicated groups and the group of 6-year-old children, respectively: 4- and 5-year-olds ($p \leq 0.163378$), 4- and 6-year-olds ($p \leq 0.000011$) and 5- and 6-year-olds ($p \leq 0.000014$).

The data objectify the conclusion that in children with typical development the period of 4–6 years coincides with the beginning of the formation of the manual dynamic praxis. Due to the sharp improvement in praxis skills, the age of 6 years should be considered critical for the development and control of successive motor programs and the brain departments responsible for them.

Information about the dynamics in the mechanisms and stages of formation of the dynamic praxis is presented by the data from **Table 3**. They reflect the quantitative distribution of the ways of performing the tasks and the age changes in them. The conclusion that dynamic praxis is least developed in 4-year-old children is confirmed, most of whom (39%) perform the two-component program after the second demonstration, and one third (33%) master the program of three movements only in conditions of joint implementation. The positive changes in 5-year-olds are mainly related to the improved implementation of the two-element program, as more than half of the children (56%) implement this program after the first demonstration. At the same time, the three-element program continues to be dominated by the joint implementation criterion (27%). Despite the fact that at the age of 5 the number of children who mastered the three-element program after the first demonstration increased, the results of the criterion for joint implementation still prevailed. Significant changes in the state of dynamic praxis are registered after the age of 6, which is confirmed by the growing number of performances after the first demonstration: 76% implementation of the two-element program and 36% implementation of the three-element program. There is also a significant reduction in cases of joint implementation (5%) and especially the performance with verbal comment (3%).

The presented data provide indirect information about the stage of formation of the functional system of dynamic praxis. They show that at the age of 4 years the brain structures associated with the realization of motor series are organized on a generalized principle, which after the age of 5 begins to be replaced by a process of gradual specialization. The significant change in the results during the period 6–7 years is a reason to consider this age as sensitive for the development of the dynamic praxis and the formation of the bilateral fronto-parietal neural complexes.

According to the influence of the demographic factor, the best development of the dynamic praxis is shown by the children from a big city, significantly ahead of those from the capital and the small town (**Table 2**). To some extent, this did not confirm the expectation of a leading place for children from the capital in terms of neuropsychological development. Although the facts need further study, it can be assumed that in contrast to the moderately populated, places with a very high concentration of population do not have the necessary stimulating effect on the cerebral ontogenesis of motor and executive functions of children. In our opinion, the causes are complex, including a variety of factors with different effects on early cerebral ontogenesis. This corresponds to the cited theories of the specific interaction of biological and social factors and the impact of the environment on the exposure to genetically determined heterochrony, leading to a variety of individual variants of development.

Although less pronounced, the statistically significant influence of the gender factor is due to the higher results of girls, and their presence indicates the connection of this factor with the development of complex praxis functions. This conclusion is complemented by the similar influence of gender on the performance of the sample for spatial postural praxis. Therefore, the fronto-parietal nerve connections and the mirror nervous system of girls undergo faster development, the effect of which may have preferences for various manual activities.

Qualitative analysis of the results leads to the following conclusions: available for children at 4 years is the shortened version of the sample for dynamic practice, while the implementation of the three-element version is associated with many gaps and motor perseverations; 5-year-olds do better with the complex version of the test, but the transcoding of spatio-temporal representations in motor programs is slow, movements are stiff and require maximum concentration; in children at the age of 6 the recoding of motor representations is significantly improved, the performance becomes more accurate, there is an opportunity for self-control and correction of errors.

Statistical analysis of the **ideomotor praxis** sample showed a significant influence of the same three independent factors: age ($F = 23.44$; $p < 0.000$), demographic conditions ($F = 8.142$; $p < 0.000$) and gender ($F = 6640$; $p < 0.010$). The leading influence of the age factor is again related to the gradual improvement of the results of the tasks and to the presence of statistically significant differences between each of the two age averages (**Table 4**). This is complemented by the quantitative distribution of data on the individual criteria for sample performance: Proper performance, Mirror performance and Wrong performance (**Table 6**).

The observed age trend is associated with a transition from a predominant mirror performance in children at 4 years (34%) to proper performance in children on 5 and 6 years. The close percentage results of the three types of performance at the age of 4 years speak of a generalized principle of organization of the brain mechanisms, characteristic in the performance of the test for dynamic praxis. It is replaced by processes of gradual specialization of the motor areas related to motor imitations (parietal and frontal) and leads to an increased number of proper performance in the next two age periods (44% in children at 5 years and 63% in children at 6 years). It can be assumed that the reduction of the cases of mirror and wrong execution is directly related to the active maturation of the lower parietal departments as responsible for the spatial synthesis and the ideas about one's own body. The age dynamics in the skills of children to imitate movements gives grounds to consider the age of 6 years as a sensitive period for the development of spatial postural (ideomotor) praxis.

Valuable information about age-related changes in visual-spatial orientation and ideomotor practice is provided by the comparison of each of the two age groups according to the criteria for correct, mirror and wrong performance, conducted by Student's t-test. The data show that according to the criterion for correct performance significant differences are registered between each of the two age groups: 4- and 5-year-olds ($p \leq 0.001$); 4- and 6-year-olds ($p \leq 0.001$) and 5- and 6-year-olds ($p \leq 0.001$), and their presence indicates a uniform and gradual formation of the mechanisms of spatial postural praxis in the considered age period.

According to the criterion for mirror (echopraxical) performance, the picture of the results is different due to the lack of significant differences between the groups of 4- and 5-year-olds ($p \geq 0.05$). There are significant differences in the cases of mirror performance of tasks between children aged 4 and 6 ($p \leq 0.001$), as well as between children aged 5 and 6 ($p \leq 0.001$). This means that only after the age of 6 do most of the children become able to perform mental spatial recoding of the motor image and adequate spatial synthesis of the observed movements. As the mirror performance is explained by underdevelopment of the spatial orientation, the close values according to this criterion in the first two age groups (4 and 5 years) confirm the sensitive nature of the 6-year-old age and for the development of the spatial function.

Similar to the first criterion, significant differences in the criterion for incorrect (wrong) performance of the sample are registered between each of the two age groups, respectively: between children aged 4 and 5 ($p \leq 0.001$), between children aged 4 and 6 ($p \leq 0.001$) and between children aged 5 and 6 ($p \leq 0.001$). Although it decreases with age, the presence of these cases indicates an incomplete process of formation of the scheme of the body (somatognosis), directly related to the spatial orientation in its parts (on oneself and on others). The presence of such somatotopic errors is more global in nature and is a serious indicator of future learning difficulties.

Qualitative changes in the analyzed executive functions in the period 4–6 years are explained in some neuroanatomical data showing increased growth of the posterior and anterior associative fields and increased density of neural groups (ensembles) in areas of the frontal lobe, in particular in the premotor cortex [35, 36]. Developmental changes in the bioelectrical activity of the child's brain, related to the predominant alpha rhythm and improvement of its spatial organization, are also indicated as a sign of maturation of the cerebral departments [37]. The age periods 6–7 and 9–10 years are indicated as transient for the dynamics of the alpha rhythm, which supports the conclusion about the importance of 6 years of age in the development of praxis functions.

The demographic factor has a significant impact on ideomotor praxis, which again is due to the highest average score for children from a large city and the lowest for children from the capital. Statistically significant on the Duncan test are the differences between the averages of the children from the capital and from a big city ($p \leq 0.001127$), as well as children from a small town and a big city ($p \leq 0.027192$). The similar results for the influence of the demographic factor on the two types of praxis functions in the considered period confirm the need for more in-depth research on the relationship of social factors and neuropsychological development in childhood.

The results for the influence of gender on the spatial orientation and ideomotor praxis are similar to those in the dynamic praxis sample and confirm the conclusion for faster maturation of the mirror nervous system and fronto-parietal neural ensembles in girls.

The specificity of the samples confirms the action of the heterochronous principle of neuropsychic development. The main evidence for this is the different dynamics of the formation of the studied functions, related to the faster development of the neurophysiological organization of the spatial postural praxis in comparison with that of the dynamic praxis. One of the reasons is the slower maturation of the structures of the frontal lobe, responsible for recoding and realization of the spatio-temporal parameters of the complex serial movements. This is confirmed by the results for correct performance of the two groups of tasks in in children at 6 years: 63% for ideomotor praxis and 36% for the complicated variant of dynamic praxis.

The observed age trend shows the variety of individual differences in children with typical development, as well as the fact that a large part of them enter school with insufficiently developed praxis skills.

6. Conclusion

The state of praxis functions in preschool has important diagnostic and prognostic significance for child development. Their implementation involves preserving the spatial parameters of visually perceived motor models with subsequent recoding in motor programs, which makes it an objective criterion for the formation and dynamics of fronto-parietal neural networks and structures of the mirror nervous system. The formation of complex praxis functions is influenced by three independent factors - age, demographic conditions and gender. The leading role of the age factor proves the determining effect of neurobiological changes on the neuropsychological development of the child. The leading role of the age factor proves the determining effect of the dynamics of neurophysiological changes on the neuropsychological development of the child. The heterochronous principle to which this development is subject explains the uneven nature of the formation of praxis functions, in particular those of dynamic and spatial postural praxis. Another reflection of it is the great variability and diversity in the rate of maturation of the brain departments responsible for the realization of these functions.

The influence of the age factor is related to qualitative changes in the motor skills of children, most pronounced at the age of 6 years, which defines it as critical for the formation of complex praxis functions. The variability and individual dynamics of neuropsychological development determine the differences in the functioning of the practice and objectify the need for its inclusion in the complex assessment of children. The registration of cases of delayed formation of praxis functions in the preschool period will lead to the development of stimulant therapy and overcoming future learning difficulties.

Conflict of interest

The authors declare that there is no conflict of interest.

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