Chapter 2

The Dynamic Maturation Process of the Brain Structures, Visual System and Their Connections to the Structures of the Prefrontal Cortex during 4–6 Years of Age

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Additional information is available at the end of the chapter

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Abstract

The chapter summarizes an author's research in the field of child neuropsychology, devoted to the dynamics of non-verbal visual gnosis in 365 children aged 4–6 with typical development. Data from a study of perceptual operations in difficult conditions (a sample to identify incomplete images), the deficits in which they are considered as a predictor of dyslexia, are analyzed. Against the backdrop of a predominantly analytical (left brain) strategy in the processing of visual incentives, a progressive improvement in the holistic (right brain) strategy was also noted, especially in children aged 6. The positive dynamics of identifying visual stimuli in difficult conditions by integrating distinct signs in the 4–6-year period is explained both by the activation of the holistic processing strategy and by the increasing participation of the prefrontal cortex in the functioning of the complex forms of non-verbal visual gnosis.

Keywords: non-verbal visual gnosis, incomplete images, dorsal and ventral visual system, pre-school age, holistic visual information processing strategy, specific learning disability, prefrontal cortex

1. Introduction

In recent years, a new field of neuropsychology of individual differences has actively developed in child neuropsychology. Its aim is to record (register) the age norms of neuropsychic functioning, the sensational periods and the dynamics of the formation of the higher psychic functions within the broad framework of typical child development. The pre-school period is sensational to many of the higher psychic functions, which explains the author's interest in it. The rapid rates of genetically determined neurophysiological changes in children are the cause of the heterochronic nature of mental development and its individual variations. The main regularity of the period is the emergence of a wide range of new psychic qualities (intellectual, sensorimotor, linguistic and behavioral) resulting from the complex interaction of biological factors and the social requirements of the environment. Individual rates and partial deficits of neuropsychic development in childhood are one of the main goals of diagnostics as they form the group of children at academic risk.

Indications of delay in pre-literacy skills (both verbal and non-verbal) are predictors of the likely development of specific learning disabilities (specific dyslexia), one of the most prevalent school-age syndromes with increasing incidence rates. The question of his etiology and neuropsychological determinants is still open. The most common manifestations of dyslexia are associated with a disorder in phonological processes, as it is assumed that pre-school phonological skills predict future reading skills [1–3]. At the same time, a number of authors [4–11] maintain the thesis of the leading influence on the difficulties in reading the violations in visual processes (visual search and scanning tasks, selective visual attention, visuospatial attention and visual memory). There are also those who highlight the role of motor difficulties on the academic problems of children [12, 13]. Separate developments examine the symptoms of dyslexia as a result of complex sensorimotor disorders in combination with phonological deficits [14–16]. Data from longitudinal neurobiology studies of children with typical and atypical reading support the thesis of non-typical brain maturation, the features of which refer to the preliterate stage [17]. Some authors [18] pay special attention to persistent silent reading disabilities in primary school pupils, linking them to the complex influence of deficiencies in lexical-grammatical operations, difficulties in non-verbal visual perceptions and limited volume of iconic memory.

We maintain the view [19] that dyslexia is more accurately conceptualized as a complex interaction of different risk and protective factors, and each of these factors can vary across different individuals with dyslexia. It may be that inefficient auditory and phonological neural systems cause reading difficulties in one individual with dyslexia, but another individual may struggle as a result of predominant visual-orthographic integration problems. Literary analysis of the problem summarizes the following facts of the current research: the core neurobiological cause of dyslexia is still not fully understood; at-risk pre-readers display reliable left temporo-parietal and occipito-temporal differences and early connectivity problems fit with a multifactorial theory of dyslexia [20].

The prognostic value of neuropsychological diagnostics in childhood allows the early application of therapeutic strategies tailored to the nature and mechanisms of developmental deficits. Since non-verbal forms of visual gnosis have the earliest debut in childhood development, the dynamics of their formation can be seen as one of the neurophysiological prerequisites for school readiness. This is most relevant to the functioning of complex gnostic operations associated with the identification of visual stimuli in difficult conditions. Their ontogenetic aspects are poorly developed from a neuropsychological point of view, which explains the need for a careful analysis of their condition during the pre-school period.

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2. Cortical organization of the processes of visual gnosis

Visual gnosis is a high mental function with very rapid development in early and pre-school age. It is one of the most sensitive indicators in the assessment of child development, and the deficits in its formation lead to specific problems in learning [21, 22]. The operation of visual gnosis has traditionally been associated with cortical associative posterior visual areas and in particular with the operation of both visual streams, vertical and dorsal. They start from the primary visual cortex (V1) and are a continuation of parvocellular (P-type cells) and magnocellular (M-type cells) pathways that bind ganglion cells of the retina with the striate cortex [23]. The ventral tract reaches the temporal-occipital zone, also called "What?" zone, and the dorsal is directed toward the parietal-temporal zone, labeled as "Where?" zone. The dorsal stream serves the analysis of visual motion and visual control of action. The ventral stream is involved in the perception of the visual world and the recognition of objects. In recent years, neuroimaging data identify the prefrontal cortex as a place to integrate visual information processed by the dorsal and ventral flow. This is supported by visual object recognition studies using degraded visual stimuli [24].

Neuropsychological studies traditionally suggest that visual object perception involves several processing stages. Most classical models distinguish between visual identification in the perception stage, which processes presented objects, and the memory stage, which verifies the resulting perceptual representations against representations stored in memory. The perception stage involves part-based analysis and analysis of global forms (feature extraction, segmentation and shape analysis). The memory stage perceptual information is matched to each form stored in memory, which includes memory about the form of an object, its semantic properties and its name [25]. The authors note that subtle perceptual deficits can produce naming problems, even when there is good access to associated semantic knowledge. Contemporary neuroimaging studies indicate that involvement of the right medial occipito-temporal region in the perceptual stage is consistent with the established role of this region in visual object recognition. On the other hand, the memory stage was characterized by the involvement of the posterior part of the rostral medial frontal cortex. It is assumed that this part of the frontal cortex is likely to be relevant in the monitoring process for the confirmation of recognition [24]. Depending on the nature of the stimuli and the cognitive tasks, visual recognition is performed with the participation of various types of memory related to the activity of various neural systems [26]. When recognizing known objects, the modality-specific cortex fields are mainly involved, whereas in difficult-to-recognize stimuli, processes rely on long-term memory information and are implemented with the participation of executive functions.

To explain deficiencies in dyslexia, Levashov [27] develops a model of visual perception. According to the model, with each eye fixation on a particular stimulus, the visual system decides three basic tasks sequentially: builds a map of areas of attention; analyzes familiar objects in them; visually decodes the visible scene; and makes spatial analysis of the objects. The right- and left-hemispheres process differently each input image by sharing results only when solving specific and complex tasks. Processes of attention during performance are related to the dorsal part of the parietal cortex, which suggests that it manages the parameter of so-called "caution."

Visual analysis in difficult conditions (recognition of imposed shapes and incomplete images) is only possible in a time-shared hemisphere interaction from left to right, where the same object is analyzed first on the left and then on the right hemisphere. Levashov suggests the following possible scheme of this interaction in the resolution of visual tasks:

1. The visually received image is processed by the left-hemisphere mechanisms for schematic recognition (classification). In cases of insufficiently known objects, inter-hemispheric associative links and corresponding structures from the right hemisphere are activated. Engaging a certain area of memory naturally narrows the search area among the engrams in long-term viewing memory.
2. The view is moved so that the projection of the analyzed plot falls into the right hemisphere in which the visual working memory is concentrated and neural structures (engrams) of each object class are stored. The input image is matched with the activated animations and leads to the categorization of the object. In complex and weakly known objects, recognition is done by moving the view to other informative points from them.

Through studies with event-related potentials in identifying hierarchical visual stimuli [28], two types of recognition are distinguished—local and global. Local-level recognition is related to the activity of the inferior temporal and prefrontal cortex of the right hemisphere and leads to an assessment of the sensory qualities of the stimuli. At the global-level recognition, the activity of the parietal cortex of the right hemisphere is guided by the inclusion of mechanisms of early sensory selection. Global perception is supposed to be related to the operation of the dorsal visual system and the spatial analysis of the objects. In contrast, perception on a local level (ventral visual system) is directed to the analysis of the elements and properties of the objects. According to some authors [29] of the initial stages of visual perception, the processes are not sufficiently lateralized. They become such at the higher levels of visual analysis when stimulus processing acquires asymmetric organization.

In recent years, the role of feedback on the functioning of cognitive processes has been increasingly discussed. The data show feedback between secondary and primary vision fields and demonstrate the modulation action of the top-down mechanism [30, 31]. Reverse connections are assumed to stimulate the activity and spatio-temporal dynamics of large groups of neurons associated with the integration of visual information.

3. Particularities of non-verbal visual gnosis in the pre-school period

Ontogenetic research has made a major contribution to the study of visual perception. They define the stages of its formation, taking into account the mechanism of heterochronic maturation of brain structures. The data show that the transition from 5 to 6 to 7–8 years of age should be seen as a period of intense maturation of the fields related to visual information analysis. At the same time, complicated forms of visual gnosis (identifying images in difficult conditions) are not sufficiently developed due to the later inclusion of regulatory brain mechanisms.

Event-related potential studies of children with a typical development show significant differences in the system of perception of visual information before and after age 5 [32, 33]. It is found that at earlier stages the visual perception processes have diffuse characters, since similar reactive and configuration event-related potentials are recorded in all caudal regions. This explains the difficulties of the children in tasks to integrate signs and reproduce the overall images of objects [34]. After 5 years of age, a process of structuring and lateralization of visual perception processes begins. This is evidenced by differences in reactivity to individual components of event-related potentials in the projection and associative visual areas of the cortex. The data show an increasing specialization of post-center associative departments in the processing of complex visual stimuli, which improves analysis and discrimination of features when forms and building standards for complex images are compared.

In the period of 5–6 years, changes in the structural organization of neuronal ensembles in the caudal cerebral regions result in a qualitatively new functional organization of visual perception [35]. In children aged 6–7 years, in the realization of visual gnosis are included structures of the frontal partition, which is the beginning of its intellectualization. The identification of difficult-to-verbalize stimuli is associated with greater reactivity of structures from the temporal and occipital parts. When recognizing stimuli with a simple verbal formulation, the reactivity is shifted to the frontal lobe.

Dorsolateral prefrontal cortex is a high regulatory center and plays an important role in manipulating visual information. The insufficient maturity of the dorsolateral mechanisms during this period explains the weak reactivity of the negative wave, reflecting the cognitive component of visual recognition. The limited involvement of the prefrontal cortex in the analysis of incomplete images suggests a poor development of the regulatory component of perception during pre-school age. New research suggests that the complex of P200-N250 waves in the visual cortex, which is considered to be key in recognizing signs, shows a significant increase in the caudal and precentral cortical divisions after 7–8 years of age [36, 37]. In adults, it is most expressed in the post-temporal parts, which are part of the ventral visual system and play a major role in recognizing fragmented images.

Neurophysiological studies in complicated perceptual conditions of children show a leading activity of the occipital segments and a lack of significant increase in event-related potentials in the post-temporal regions [38, 39]. It is also stressed that at the age of 5–6 years, components of event-related potentials in the prefrontal cortex are not recorded. According to some authors [35], the low efficiency of fragmented image identification in this period is due to both the immaturity of the prefrontal cortex and the deficiencies in the functioning of the visual system. The low level of recognition under conditions of perceptual deficit is explained by the underdevelopment of regulatory mechanisms and insufficient involvement of the ventral visual system. In the period of 7–8 years, the role of the ventral visual system increases; this corresponds to the morphological data for significant transformations in the neuronal organization of the posterior temporal areas [39]. There is currently no unified opinion on the mechanisms of recognizing incomplete images in children. According to neurophysiological data in the period of pre-school and early school age in their brain organization there are both similarities and differences. Similarities refer to prefrontal cortex involvement in early stages of the analysis of complex visual stimuli.

The differences reflect the underdevelopment of the regulatory components of visual recognition in the pre-school period, shown by the large number of mistakes in children aged 5–6 [34].

Testing through event-related potentials for perceiving fragmented shapes in children aged 5–6 years separates two subgroups: A subgroup with a small number of errors and a B subgroup with a large number of errors [26]. In the second subgroup, a delayed development of two systems was recorded: the ventrolateral visual system and the dorsolateral prefrontal cortex responsible for regulatory functions and in particular for inhibitory control. Inhibitory control determines the successful recognition of the figures, whereas its absence explains the impulsive responses of children with low scores. The conclusion is that the morpho-functional maturity of the neuron systems processing sensory information and the state of regulatory functions determine children's individual abilities to visual recognition and their readiness for school education.

The image identification in conditions of sign shortness assesses the functioning of the right-hemisphere mechanisms and the implementation of a holistic perceptive strategy and is one of the most complex gnostic tasks. Difficulties in building hypotheses by children explain the cases of refusal to name individual figures and the presence of perseverations (use of a single word for different images).

The analysis of the existing data sets the period of 4–6 years as sensitive for the development of brain mechanisms for perceptive processing and for the formation of complex forms of visual gnosis. The specifics in the functioning of the gnostic operations in children with typical development in pre-school age have an important diagnostic and prognostic significance since the evocation of normative data allows for the separation of subgroups with different levels of perceptual functions and the differentiation of children at risk of learning difficulties. This is in line with the thesis [40] that any neuropsychological study in childhood pursues two purposes: the diagnosis of the condition of the function and the formulation of the treatment methods and approaches.

4. Description of the research

4.1. Aim

Assessment of the condition of complex forms of non-verbal visual gnosis in children with typical development at pre-school age and differentiation of subgroups with different levels of functioning of perceptive processes.

4.2. Method

For the study of visual gnosis under difficult conditions, the neuropsychological probe "Recognition of incomplete images" was used. The sample is based on the holistic principle of sensory integration and is widely used [26, 41]. In a manner of implementation, it is close to the image recognition test with a decreasing degree of fragmentation [42, 37].

As mentioned above, task execution activates the occipito-temporal part of the right hemisphere (ventral visual system) and prefrontal cortex. The results of recognizing objects in conditions of shortness of signs provide information on the state and dynamics of the functioning of these

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regions. Neural processes responsible for mental "filling--in" the missing information in visual incentives, some authors [37] mean by the term "perception of closing". The phenomenon is a combination of areas known as the lateral-occipital complex (LOC) that is linked to a wide network of dorsal and frontal regions. Studies with functional magnetic resonance imaging (fMRI) confirm the leading role of the lateral-occipital complex in detecting hidden objects [43].

The sample we use contains 12 black and white incomplete images of objects (lamp, sword, spoon, anchor, pliers, kettle, teapot, needle, key, guitar, scissors and ring). Some of them are presented below (**Figures 1–4**).

Figure 1. Lamp.

Figure 2. Anchor.

Figure 3. Teapot.

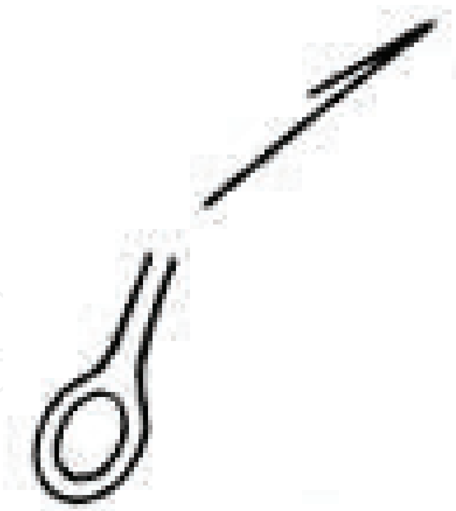

Figure 4. Scissors.

The investigation is individual and the answers are put in a separate protocol. Children look consistently at each of the stimuli and name it. All answers are noted regardless of their nature (correct or incorrect).

Assessment criteria:

- correct naming of an object—5 points,
- replacement of the name with a functional description of the object—4 points,
- wrong answers due to perceptual similarity—perceptively close (for instance instead of "pliers"—"scissors" and "spoon"—"shovel")—3 points,
- wrong answers due to association with one element of the image—fragmentary (for instance instead of "ring"—headphones"; "key"—"path")—2 points,
- wrong answers without perceptual similarity—perceptively distant ("kettle"—"chicken," "elephant"; "scissors"—"spoon")—1 point,
- without answer (does not name)—0 points.

The features of the functional system of visual perception are determined by indicators such as accuracy, completeness, volume and time for perception. In our case accuracy of perception is measured by using two parameters: number of correct answers and typology of the incorrect answers.

A total of 365 typically developing children without diagnosis of visual disorders took part in the research. All children attend state nursery schools and have Bulgarian as the mother tongue. They form three age groups: 4-year-olds (116 children); 5-year-olds (128 children); and 6-year-olds (121 children). Besides the age factor, the children were separated according to the size of settlement they live in (demographic criterion)—195 children from the capital, 90 living in a big city and 80—in a small town. The proportion according to gender is 173 males and 192 females.

The results are operated with a tri-factor dispersion analysis.

5. Results

The values of the F-criteria and the confidence probability (P) indicate that the two independent factors, age ($F = 15.75$; $p < 0.000$) and the location (settlement), ($F = 4.89$; $p < 0.008$) have a statistically significant impact on the dependent variable for recognizing incomplete images. There is also a significant impact of the paired interaction, Age*Settlement ($F = 3.93$; $p < 0.003$) and Age*Gender ($F = 3.7$; $p < 0.026$).

The profile of the age factor shows a graduate growth in the score for the test, most prominent for the 5-year-olds. The biggest differences are the average scores for children aged 4 and 5 (**Figure 5**), which emphasize the importance of the fifth year for the dynamics of the neuropsychic development.

Duncan's test establishes statistically significant differences between any two means (**Table 1**).

The influence and profile of the demographic factor on the development of the gnosis functions become obvious from the higher summarized score of the children from the big city (**Figure 6**). The average score of the children in the capital is lower, and the lowest is that of children from a small town. There is a statistical significant difference only between the average results of children from a large and a small town. The difference between the average points of children from a big city and capital is close to significance ($p = 0.055$), and among the children from a capital city and a small town the differences are not credible (**Table 2**).

Attention is paid to the interaction of age and gender factors. The data show identical average scores for girls and boys at 4 years of age, as well as similar ones for children at 5 years of age. Significant gender differences are only recorded in 6-year-olds. Duncan's test demonstrates the influence of both factors through specific differences between pairs of means (**Table 3**).

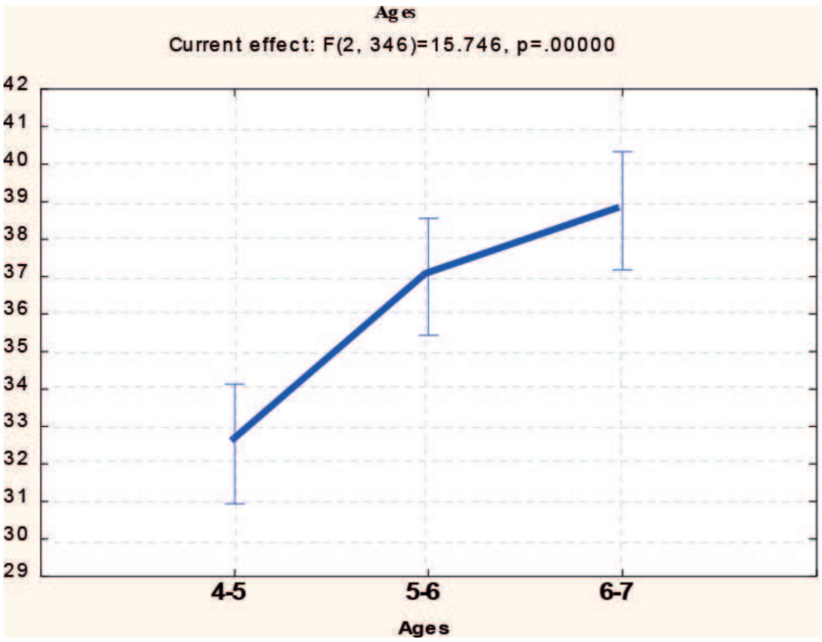

Figure 5. Effect of age factor on the results of recognizing incomplete images.

Ages	{1}–32.313	{2}–36.890	{3}–39.467
4 years		**0.000019**	**0.000011**
5 years	**0.000019**		**0.013385**
6 years	**0.000011**	**0.013385**	

Table 1. Significance of the average scores' differences of the children from each age group.

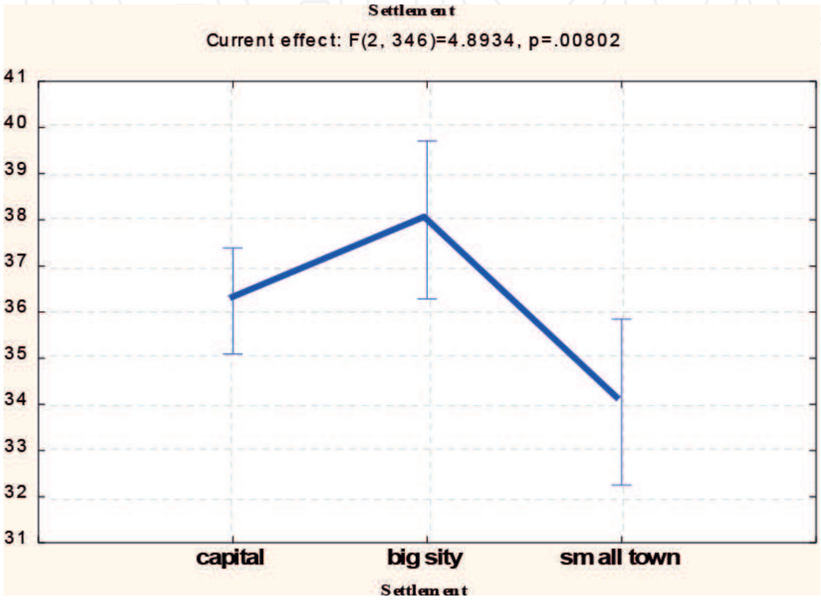

Figure 6. Effect of settlement factor on the results of recognizing incomplete images.

Settlement	{1}–36.412	{2}–37.900	{3}–34.263
Capital		0.185263	0.055564
Big city	0.185263		**0.001722**
Small town	0.055564	**0.001722**	

Table 2. Significance of the average scores' differences of the children from the three types of settlements.

Between groups of boys and girls at the age of 4 and 5, credible differences are not observed. The presence of credible differences between those aged 6 years ($p \leq 0.022$) is due to the higher mean values than girls.

Table 4 represents the percentage distribution of the correct answers and of the types of wrong answers (perceptively close, fragmented, perceptively distant and without answers) of the children from each age group. The data allow a more in-depth qualitative analysis of the condition and dynamics of complex forms of non-verbal visual gnosis in children with typical development from pre-school age.

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Ages	Gender	{1}–32.621	{2}–32.000	{3}–36.649	{4}–37.086	{5}–41.129	{6}–37.750
4	Girls		0.674	0.006	0.004	0.000	0.001
4	Boys	0.674		0.002	0.001	0.000	0.000
5	Girls	**0.006**	**0.002**		0.767	0.004	0.486
5	Boys	**0.004**	**0.001**	0.767		0.009	0.653
6	Girls	**0.000**	**0.000**	**0.004**	**0.009**		0.022
6	Boys	**0.001**	**0.000**	0.486	0.653	**0.022**	

Table 3. Significance of the average scores' differences of the children of different gender and different ages.

Ages	True answers	Perceptively close	Fragmented	Perceptively distant	Without answers
4 years	28%	21%	10%	23%	18%
5 years	36%	21%	13%	17%	13%
6 years	46%	21%	9%	11%	13%

Table 4. Distribution of the type of answers for incomplete images for all age group children.

6. Discussion

The statistical analysis shows a leading influence on the development of complex forms of non-verbal visual gnosis of age and settlement (demographic) factors. The state of perceptive skills under difficult conditions is characterized by a positive age dynamics and a progressive increase in properly recognized figures. This is confirmed by the results of Duncan's test (**Table 1**) for the presence of meaningful differences between two age groups of children: 4- and 5-year-olds ($p \leq 0.000019$), 4- and 6-year-olds ($p \leq 0, 000011$) and 5- and 6-year-olds ($p \leq 0.013385$). The data support the thesis of improving the right-brain holistic strategy of stimulus processing and the increasing involvement of prefrontal cortex in the processes of visual perception.

The significant increase in correct responses in children at 5 years shows the particular place of this period in the general neuropsychic development. In terms of visual gnosis, the period is characterized by increasing specialization of the post-central associative regions, improving the performance of the ventral visual system in conditions of deficiency of signs [34, 35] and gradual inclusion of the regulatory mechanisms of the prefrontal cortex. We assume that the age range of 4–6 years can be considered as sensitive for the development of complex perceptive functions and the cases of delay in their formation as prognostic markers for future learning difficulties.

The proven influence of the demographic background on the development of non-verbal visual gnosis confirms the thesis of the specific interaction of biological and social factors within the framework of the neuropsychic functioning. Data show the highest average results for children from a big city, followed by a capital and a small town. According to statistical analysis (**Table 2**), there are significant differences only between the results of children from a big city and a small town ($p < 0.001722$).

The interactions of the biological factors, age and gender, have a particular place in the development of complex forms of visual gnosis (**Table 3**). The statistical analysis does not show significant differences in recognizing incomplete images between girls and boys at the age of 4 and 5 years. These are only evident in children at 6 years of age. The observed differences are explained by the higher mean values of the girls—a fact that is indicative of gender influence on the neuropsychic development of these children. It can be assumed that in girls the ventral visual system and the neural complexes of the prefrontal cortex develop faster, the signs of which become obvious at the end of the pre-school period and explain the better functioning of perceptual and controlling functions.

The qualitative analysis of the results is based on the responses of the children differentiated in several types: correct answers, wrong answers based on perceptive similarities (perceptually close), wrong answers due to one element recognition (fragmentary), wrong answers without perceptive similarities (perceptively distant) or no answers. It is assumed [41] that when recognizing unfinished images, the child must remember the elements and connect them to those memory engrams that contain similar signs. In cases of the complete match between them, the object is recognized correctly. In the case of partial correspondence errors are observed on the basis of close or distant similarity. When the child does not count all, but only the individual signs of the image, the errors are of a fragmentary type. If there is no answer, the reasons are two: missing engrams in memory or an inability to generate an adequate perceptive hypothesis. Errors of perceptual similarity are defined as lighter and fragmented and perceptually distant as heavier.

After a study of a large child population, Ahutina and Pylaeva [41] conclude that perceptually close errors have left-brain mechanisms and are due to weaknesses in the analytical processing of visual information. Fragmented types of wrong answers are explained by right-brain deficits of holistic processing, because on one or two fragments the child draws the conclusion of the whole image. Perceptively distant wrong answers are associated with right-brain or bilateral weakness.

Here are examples illustrating the different types of wrong answers in our survey.

Wrong answers based on perceptual similarity: saber—“knife”; spoon— “shovel,” “broom”; water can—“shower”; pliers—“scissors.”

Wrong fragmentary-type responses: anchor—“arrow,” “hanger”; kettle—“bird,” “pig”; needle—“hand,” “figure,” “pinch.”

Perceptively distant wrong answers: sword—“octopus,” “spoon,” “trunk”; spoon—“man,” “rod,” “umbrella”; scissors—“magnifying glass,” “needle”; ring—“headphones,” “banana,” “heart,” “river.”

The quantitative distribution of all responses in the 4–6 years of age period provides valuable information on the ontogenesis of cortical mechanisms in perceptual processing under difficult conditions (**Table 4**). Data show that children at 4 years only recognize truly 28% of the images, with similar results of perceptively close (21%) and perceptively distant (23%) responses. In 18% of cases, there was a lack of response. The results support the thesis of incomplete functioning of the ventral visual system, hampering the holistic processing of stimuli and underdevelopment of prefrontal areas, resulting in a large number of impulsive responses.

Significantly higher results in children at 5 years confirm the presence of evident age dynamics in the development of gnosis functions. Against the backdrop of an increased proportion of correct recognized figures (36%), the proportion of perceptually distant answers (17%) and lack of response (13%) decreased. Perceptually close responses remain the same (21%). A significant improvement in perceptual abilities is the reason why the fifth year is considered critical for neuropsychic development.

Similarly to the 5-year-olds, the distribution of the types of responses remains in children at 6 years: the number of faithfully recognized figures (46%) increased and perceptibly reduced distant answers (11%). The ratio of perceptually close errors remains unchanged (21%). The data support the thesis [38] that the transition from 5 to 6 to 6–7 years is a time of intensive maturation of the systems, providing visual information analysis and significant changes in the organization of the neural ensembles in the caudal cortex. Despite the positive changes, the number of faithfully recognized figures in children at 6 years does not exceed half of all answers—a fact that is supported by data [35] of insufficient maturity of the prefrontal cortex and the cortical sections of the visual system (in particular the ventral visual system) during 4–6 years.

The summarized results clearly outline the age dynamics of visual perceptions under difficult conditions. If the number of faithful and perceptively distant answers prevails in children at 4 years of age, the number of correct and perceptively close answers prevails over the age of 5 and 6 years. The ratio of responses to perceptual closeness does not change over the three age sub-periods, while perceptibly distant reductions are significantly reduced from 4 to 6 years of age. The results could also be explained by the abovementioned data on the diffused nature of visual perceptual processes before the age of 5.

The impact of the demographic factor on the distribution of responses is as follows: in the capital, perceptually distant answers and cases of lack of response are leading; in the big city the perceived errors and lack of responsiveness predominate; in the small town the leading place occupies the replaced by a perceptively close and perceptively distant similarity. Existing analyzes [41] give reason to assume that the mistakes in the capital are mainly due to right-brain difficulties, in the big city, it is the left-brain difficulties, and in the small town, the mistakes are related to both types of difficulties. This is supported by the better functioning of holistic right-hemispheric mechanisms and higher outcomes of children from a big city.

The additionally outlined age norms for the accomplishment of the sample to recognize unfinished images show interesting tendencies of prognostic nature. They are determined by the children's individual results and lead to the separation of three subgroups: leading group, medium group and behind group. Their distribution in the direction of 4- to 5- and 6-year-old children is as follows: leading group: 30–28–27%; medium group: 45–46–47%; and behind group: 25–26–26%. It is noteworthy that the state of subgroups during the various stages of pre-school age is practically unchanged. We believe that this fact has important prognostic significance and allows an early diagnosis of deficits in complex forms of visual gnosis.

Particular attention is paid to the results of the 6-year-old children who are about to go to school. Exported data show that one-fourth of them fall behind a group characterized by the incomplete processing of the right-brain ventral visual system and insufficient involvement of control functions of the prefrontal regions. The engrames of objects in long-term memory are not sufficiently built up, making it difficult to form proper perceptive hypotheses. We assume that children in this group will face obvious difficulties in recognizing and differentiating graphical characters (alphanumeric, numeric and geometric), allowing them to be identified as a risk group for specific learning disorders (dyslexia).

The unsatisfactory development of the complex forms of visual perception could be viewed as a predictor for future reading difficulties and proves the diagnostic and prognostic validity of the sample to recognize incomplete images for the pre-school age period.

7. Conclusion

The analysis of the represented data shows that for the age period 4–6 there is a process of dynamic maturation of the right-brain structures of the ventral visual system and their connections to the structures of the prefrontal cortex, leading to gradual improvement of the children's abilities for visual discrimination of objects in difficult circumstances (incomplete images). Impact on the development of complex forms of non-verbal visual gnosis has the combination of age, demographic and gender factors, among which a special place is the age of 5 years. The positive dynamics of the mechanisms of holistic processing of complex non-verbal stimuli started in the pre-school period, but their formation continued in the next stages. Particular attention is paid to the fact that over the 6-year period most of the children with typical development continue to show great difficulty in recognizing incomplete images. They enroll at school with underdeveloped perceptual and control functions, which is why the group should be considered as risky for the development of dyslexic symptoms.

The neuropsychological probe "Recognition of incomplete images" is a sensitized option for the diagnosis of non-verbal visual gnosis in childhood. It has a high prognostic value and allows an early detection of cases of delayed development within the broad childhood norm. The application of the task (in isolation or in combination with others) supplemented by a competent quantitative and qualitative analysis responds to the leading tendencies in modern child neuropsychology and allows the timely identification of children at risk of learning difficulties.

Conflict of interest

Author declares no conflict of interests.

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