Psychology & Neuroscience
ISSN: 1984-3054
landeira@puc-rio.br
Pontifícia Universidade Católica do Rio de Janeiro
Brasil

PSYCHOLOGY & NEUROSCIENCE

Psychology & Neuroscience, 2014, 7, 4, 453-460
DOI: 10.3922/j.psns.2014.4.04

Executive function in children with ADHD

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Abstract

The study of executive function was one of the main topics of the work of A.R. Luria. Attention-deficit/hyperactivity disorder (ADHD) presents a good model of executive disorders, the experimental study of which reveals a complex structure of executive behavior including sustaining activity and attention, selectivity in decision making, shifting, planning, and prognostic ability. Cross-cultural (Russian/Italian) differences in executive function in children with ADHD are discussed. Comparisons of ADHD in preschool and primary school children are made in an attempt to prevent the aggravation of deficits and provide early remediation. **Keywords**: A. R. Luria, neuropsychology, executive function, ADHD, preschool age.

Received 01 March 2014; received in revised form 22 July 2014; accepted 25 July 2014. Available online 16 December 2014.

The problem

Luria's concept of three functional units (blocks) of the brain (Luria, 1973) permits an understanding of the many problems associated with abnormal child development. The last unit that is maturated is the brain, providing the control and voluntary regulation of activities, later called executive function. The voluntary regulation of mental activity includes the following: (*i*) an objective setting, in accordance with motivation and the purpose of actual or planned activity, (*ii*) planning a program and the best ways to achieve a goal, (*iii*) monitoring the implementation of the program and the timely correction of inadequate actions and associations, and (*iv*) comparisons of objectives with intermediate and final results.

After the work of Luria, many studies evaluated the structure of executive function and their relationships with cognitive function (Wilkins, Shallice, & McCarthy, 1987; Nigg, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005; Diamond, 2013). Broadly defined, executive function refers to a complex set of cognitive abilities that underlie adaptive, goal-directed behaviors and enable individuals to override more automatic or established thoughts and responses (Garon, Bryson, & Smith, 2008; Diamond, 2013). At a more fine-grained level, a set of cognitive control skills (e.g., attention, inhibitory control, self-monitoring, and flexibility) is defined as specific interrelated information-processing abilities that are involved in the control and coordination of information in the service of goal-directed actions and has been studied in the cognitive development literature (Willoughby, Wirth, & Blair, 2012).

The underdevelopment of executive function lies at the core of most dysontogenesis syndromes, greatly influencing a child's behavior and learning in preschool and school (Kovalchikova, 2014).

> "A disobedient child rarely deviates from the given instructions by unwillingness to follow them. He can't just yet and doesn't know how to keep himself from an action unapproved by adults. Too large is his dependence on direct influences of the outside world; still very difficult is to predict the results of own actions, to divide in own mind the desired 'now' and the possible 'after'" (Korsakova, Mikadze, & Balashova, 2001, p. 32).

The long process of maturation of the unit of activity programming and monitoring, according to psychophysiologists, has several critical points. Above all, the crucial period is between 6 and 7 years of age when, according to electroencephalography data, a simple emotional brain activation system is replaced by the verbal voluntary control of the brain with the growing participation of the frontal lobes of the left hemisphere (Adrianov & Farber, 1990). During this critical period, the child's schooling begins. Unsurprising is that all executive functions, including programming and monitoring individual actions, forming designs and purposes of activities, and regulating behavior, are deficient in children with learning problems.

Attention-deficit/hyperactivity disorder (ADHD) is one of the most common behavioral and learning

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disorders among children and a frequent reason for seeking psychological help in childhood (Barkley, 1998; Nigg, 2005). According to the criteria of the *Diagnostic and Statistical Manual of Mental Disorders*, 4th edition, text revision (DSM-IV-TR; American Psychiatric Association, 2000), the frequency of ADHD varies from 3 to 20% (Romanchuk, 2010), and the official indicator in the DSM-IV is 3-5% (American Psychiatric Association, 2000). This means that one in 30 children has ADHD, suggesting that each class in primary school has at least one student with ADHD.

At the behavioral level, this disorder is primarily manifested by excessive and unjustified physical activity, fussiness, and impulsivity that exceed the limits of age standards, in addition to difficulties concentrating attention because of frequent switches in attention. Neuropsychological assessment identifies in these children the immaturity of various cognitive functions, including gnosis, orientation in space, and problem solving, among others (Glozman, Kurdukova, & Chibisova, 2007; Glozman, Kurdyukova, & Shevchenko, 2013; Kurdyukova, Glozman, & Chibisova 2010; Glozman, 2013).

The disorder typically occurs early in the development process, usually within the first 5 years of life. However, the peak of referrals to specialists occurs by 6 or 7 years of age when excessive, poorly organized, and poorly regulated activity becomes an obstacle to intensive training activities. Even with relatively high intellectual potential, children with ADHD are often unsuccessful at school and experience difficulties adapting socially to peers (Pennington et al., 1993; Osipova & Pankratova, 1997).

Unfortunately, despite the frequency of the syndrome, this disorder is often diagnosed late or incorrectly or not detected at all. The behavior of the child can be explained by a lack of diligent upbringing by the parents or bad character of the child, which cannot be changed. Accordingly, most children do not receive timely and necessary support. The variety of methods for ADHD assessment is substantial and differs between Russia and Western countries. Therefore, finding converging points and a theoretical foundation of the most frequently used tests is very important.

EXPERIMENTAL STUDY: PART I

The first part of our experimental study sought to select sensitive methods to reveal mechanisms of executive disorders in children with ADHD through an international study (Glozman, Marzocchi, & Kurdukova, 2012) by doing the following: (*i*) compare the discriminative value of some Lurian and Western tests for ADHD diagnosis with regard to executive function in learning-disabled primary school students, (*ii*) reveal the potential of these tests to describe the structure of executive behavior, including sustaining attention, selectivity of attention, shifting in execution, planning, recalling of performance, and error correction, and (*iii*) analyze cross-cultural differences in performance on these tests.

Methods

The present experiment used the Shulte test from the Luria battery (Luria, 1973) and a test of figure matching. Both of these instruments measure the sustaining of activity and attention. The Hayling Sentence Completion Test (Shallice, Marzocchi, Coser, del Savio, Meuter, & Rumiati, 2002) and an analogous test from the Luria battery measure selectivity in decision making. Dynamic praxis, a test of conventional reactions from the Luria battery, and the Numeric Stroop test (Marzocchi, Re, & Cornoldi, 2010) measure shifting. The problem-solving test and Everyday Planning Test (Marzocchi et al., 2010) measure the planning of steps and coherence between planning and execution. The Junior Iowa Gambling Task (Bechara, Damasio, Damasio, & Anderson, 1994) measures the ability to compare gains and loses and recall performance. The Conners Scale determines the level of ADHD (Passolt, 2004). Let us provide some details on some of the tests from the Italian battery for executive function.

Instruments

Hayling Sentence Completion Test. In this test, children must finish orally presented sentences with a missing final word that is semantically related (Part A) or completely unrelated (Part B) to the sentence. The missing words are matched for frequency and age of acquisition. Each type of answer (i.e., answers that meet or do not meet the requirements) are scored. High scores on Part B reveal a lack of selectivity.

Numeric Stroop. In this test, children are required to count numbers. The trials are divided into two sessions. The baseline session has 12 stimuli (stars), and the experimental sessions have 75 groups of identical numbers. The number of naming errors in which the child names numbers instead of counting them is recorded, in addition to the difference in time to count stars and count numbers (i.e., Interference Time) attributable to the Stroop effect.

Everyday Planning Task (EPT). This is a semi-ecological task that has two versions: a version for children between 8 and 10 years of age and a version for children between 11 and 14 years of age. The instrument includes three different tasks: memory task, time estimation task, and planning task. In the memory task, the children must recall activities (e.g., buying bread for grandmother, going to training, and doing homework) listed by the examiner in any order. In the time estimation task, the children must estimate the duration of each activity. In the planning task, the children must order 10 activities according to logical and chronological constraints in a maximum of 30 min. The children can see the list of 10 activities, and they have an answer sheet and map of the city where these activities are performed. The dependent variables are (*i*) the recall of activities in the memory task, (*ii*) the correct planning of activities (relationship between properly planned activities and number of moves required to complete them) in the planning task, (*iii*) number of rule violations, (*iv*) coherence (consistency between estimation and effective use of time in the planning task), and (*v*) time to execute the task.

Junior Iowa Gambling Task. In this task, the subjects are presented with four virtual decks of cards on a computer screen. They are told that each time they choose a card they can win some game money (a reward). However, choosing some of the cards often causes them to lose some money (a penalty). The goal of the game is to win as much money as possible. The decks differ from each other in the way that the losses are distributed. Thus, some decks are "bad decks," and other decks are "good decks," in which some cards will lead to losses over the long run, and others will lead to gains. The dependent variable is the gain or loss of money at the end of 100 cards. The Iowa Gambling Task copies daily, real-life decisions (Damasio, 1994) and has provided a strong impetus to understand the role of the emotional system in the organization of decision-making behavior (Bechara, 2005; de Visser et al., 2011; Gläscher et al., 2012).

Subjects

Thirty-seven learning-disabled (inclusion criterion) public primary school students (19 Russian and 18 Italian), 8-13 years old, were included in the study. The exclusion criteria were very low intellectual level (debility) or psychiatric pathology (e.g., depression and endogenic disease) that interferes with learning in a public school. Both samples were diagnosed with ADHD according to the criteria of the *International Statistical Classification of Diseases and Related Health Problems*, 10th revision (ICD-10; World Health Organization, 2009), using a semi-structured interview with the parents. The ADHD diagnosis was confirmed by the Conners Questionnaire for parents (Conners T score = 70). The cut-off was established as T ≥ 70. The parents provided written informed consent for assessment. Both groups were matched by age (Table 1).

Results

On the Italian Executive Function battery, Italian children showed poorer performance than Russian children on coherence to use time in the EPT, and they were faster (probably more impulsive) than the Russian children. Russian children produced more errors in the Numeric Stroop task. Italian children did not present comorbid learning disorders; therefore, the absence of comorbidity could justify their better performance compared with Russian children. We did not find significant differences in the other measures of the EPT, in interference time in the Numeric Stroop test or on the Junior Iowa Gambling Task (Table 2).

In the Russian executive function tasks, the two groups did not show significant differences in the Analogies test, but they performed significantly different on the Shulte test and Test of Conventional Reactions (Table 3).

Table 1. Subjects of the international study of ADHD.

Measure	Russian group (14 male, 5 female)	Italian group (16 male, 2 female)	*t*-test	*p*
Age	9.00 (1.00)	9.78 (1.70)	1.78	.097
Conners ADHD scale	74.79 (10.57)	78.11 (7.67)	1.87	.069

Table 2. Scores on the Italian battery of executive tests in children with ADHD.

Measure	Russian group (14 male, 5 female)	Italian group (16 male, 2 female)	*t*-test	*p*
Everyday Planning Task				
Memory	8.00 (1.53)	8.50 (1.20)	1.103	.278
Planning	0.96 (0.17)	1.05 (0.17)	1.735	.092
Violations	1.89 (2.31)	1.33 (1.19)	.923	.363
Coherence	6.68 (1.42)	4.71 (2.63)	2.479	.021*
Time	14.99 (3.86)	12.47 (3.22)	2.148	.039*
Numeric Stroop				
Errors	3.47 (2.23)	1.72 (1.36)	2.825	.008*
Interference time	-.001 (.52)	.27 (.31)	1.883	.068
Iowa Gambling Task				
Money Gain or Loss	-48.16 (77.45)	-49.17 (74.07)	.040	.968

*$p < .05$.

Table 3. Scores on the Russian battery of executive tests in children with ADHD.

Measure	Russian group (14 male, 5 female)	Italian group (16 male, 2 female)	*t*-test	*p*
Shulte Test	1.55 (.78)	.67 (.71)	3.614	.001*
Test of Conventional Reactions	.95 (.43)	.56 (.51)	2.529	.016*
Analogies Test	.40 (.44)	.17 (.38)	1.701	.098

*$p < .05$.

Therefore, the results of this first part of the study showed that the differences between children with and without ADHD were reflected by worse scores on all of the tests in the first group and qualitative differences, including the lack of step planning, the lack of comparing one's own actions with previous results, impulsivity, and difficulty recalling performance. The most discriminative instruments for groups with and without ADHD were the Numeric Stroop test and Test of Conventional Reactions. Cross-cultural differences were mostly seen in tasks that included time planning. The difference between the two groups (Russian and Italian) tended to be significant on the Conners scale, which may impact the difference in executive function between the two groups.

EXPERIMENTAL STUDY: PART II

An analysis of the corresponding literature showed that the observations in most studies were made for children of school age. This is a period when the signs of ADHD are manifested more clearly. The mechanisms of the development and manifestation of ADHD in early and preschool age remain largely outside the focus of psychologists. This is why neuropsychological assessments of children with specific needs and deficits in the development of mental function in preschool age are important for psychological and pedagogical practice. An early diagnosis and remediation should be oriented toward the preschool age when the compensatory abilities of the brain are greater and we are able to prevent persistent abnormal manifestations (Litsev, 1995; Osipenko, 1996; Haletskaya, 1999). This was the aim of our study.

Methods

The Conners Scale was used to determine the level of ADHD (Passolt, 2004). This questionnaire contains either 10 questions (short version) or 80 questions (full version) that assess behavior in children. In this study, the parents of preschoolers were given the short version of the questionnaire, whereas parents of primary school students completed the full version.

The methods of Lurian neuropsychological examination were adapted to the child population, and the results were evaluated quantitatively and qualitatively. These methods allowed us to differentiate difficulties in learning and behavior caused by underdevelopment or individual peculiarities of the functioning of brain structures (Glozman, 2013). The early development of the child was analyzed using a special questionnaire for parents.

Subjects

Nine preschool children with ADHD confirmed by a neurological assessment and the Conners Scale (Conners Scale-10 score > 15) participated in the study, with seven boys and two girls aged 3-6 years. All nine preschoolers attended a course of neuropsychological remediation at the Moscow Research Centre of Developmental Neuropsychology. A control neuropsychological follow-up was done to reveal the dynamics of the results after remediation.

In addition to this sample, 13 school children with a diagnosis of ADHD were evaluated, confirmed by neurological assessment and Conners Scale-80 data, with 11 boys and two girls aged 7-11 years.

Results

To perform a comparative analysis of the neuropsychological data in preschool and school children before remediation, we compared the data of the Lurian neuropsychological assessment before remediation between preschool and school children. School children without remediation during the preschool period showed minimal positive differences from preschoolers in gnostic and mnestic functions that can be associated with the development of children, whereas the average cumulative cognition scores remain unchanged.[1]

Many mental spheres were evaluated such as the orientation of children in time and space their general knowledge, the control of their own behavior, critical attitudes about mistakes made, and adequacy during assessment. An underdevelopment of verbal function was revealed, including expressive speech, naming, and understanding logical and grammatical structures. However, the most negative changes were observed in neurodynamic functions. For various reasons, the level of functional brain activity in children is unstable, has poor resistance to loads, and requires constant stimulation, with alternating periods of productive work

[1]In the Lurian system, higher scores indicate worse abilities.

and rest. Therefore, the working capacity of students worsens with ever-increasing loads of school work from year to year (Figure 1).

In addition to the quantitative analysis of scores on the neuropsychological assessments in both groups of children, we performed a comparative qualitative analysis of deficits in higher mental function in preschool and school children. The results are presented in Figure 2. One can see an increase in the number of deficits in the areas of speech, memory, and neurodynamics among school children compared with preschool children.

Spearman rank correlation showed that the age of the child had a significant correlation with neurodynamic indicators, memory impairment, and the ability to solve problems. This means that older children have worse scores (without remediation) for neurodynamics, memory, and the ability to solve problems.

Hyperactivity or excessive motor disinhibition is a manifestation of fatigue. A tired child, unlike an adult, cannot control the condition and needs time to rest, manifested by overdrive and reflected by chaotic subcortical excitation. Consequently, children exhibit specific changes in neurodynamic nervous processes. The mental process in children is also manifested by apparent weakness in the formation of the unit of brain activation. Defects in the neurodynamic bases of mental functions indicate that acquired information remains unstable and rapidly disappears (or is inhibited) by interfering influences, especially homogeneous influences, even with sufficient memorization ability (Glozman, 2013).

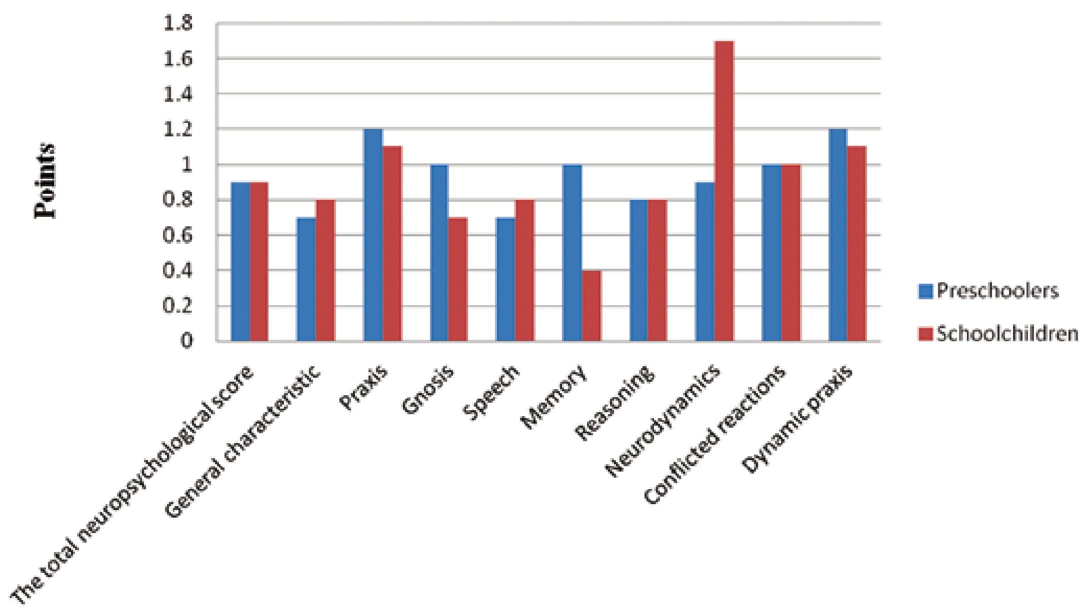

Figure 1. Comparative pattern of neuropsychological assessment data in preschool and school children with ADHD before remediation.

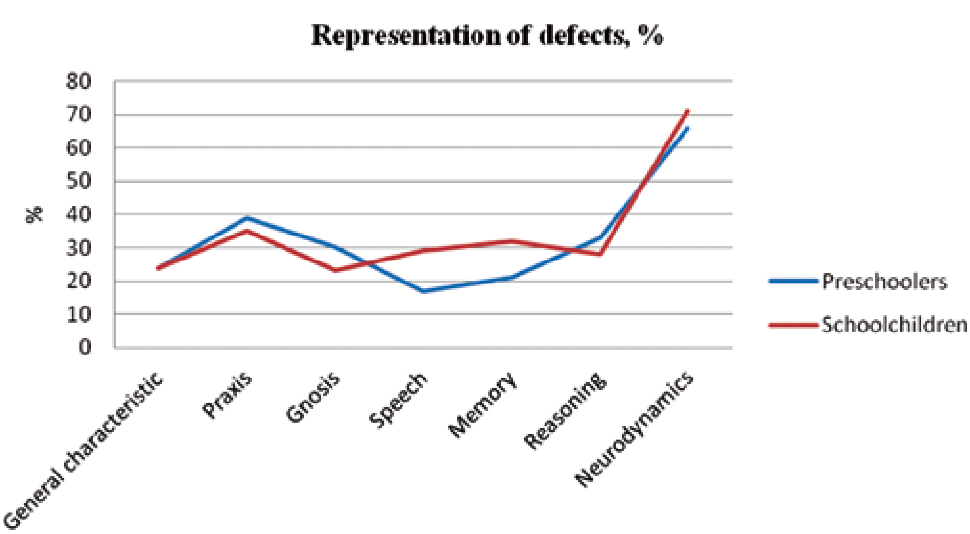

Figure 2. Percentage of deficits in preschool and school children with ADHD.

Mathematical problem solving requires planning and execution processes to achieve results. A hyperactivity disorder involves the immaturity of planning, a lack of control over one's own movements, and higher levels of movement. This affects complex multi-level action such as solving a mathematical problem, which causes great difficulty for children with ADHD.

Let us now consider the factors that aggravate cognitive underdevelopment in children with ADHD. Recent studies revealed many factors that can lead to the appearance of ADHD. This is why a multicausal theory of the development of ADHD is predominant. Biological factors, especially perinatal hypoxic lesions of the central nervous system, are the most important during the first 2 years of life. During later development, the disorder also depends on psychological and social factors such as the family situation, upbringing, and financial and social conditions (Zavadenko, Petruhin, & Solov'ev, 1997). The causes of the observed symptoms were revealed in our study through an analysis of the data of the checklist of early child development.

Significant correlations were found between children with ambidexterity and the severity of reasoning deficits, indicating the need for a specialized approach to forming intellectual function in children with incomplete dominance of the left hemisphere. Significant correlations were also found between birth pathology and quantitative praxis scores. The more noticeable birth pathologies included cord entanglement, asphyxia, hypoxia, and hypotrophy, with significant impacts on motor coordination, fine motor skills, and praxis.

Significant correlations were found between abnormal motor development during the first year of life and quantitative scores on preschooler's speech development and speech defects. The study of children with speech pathology showed that they have motor development problems that begin at a very early age. These children did not have any neurological motor symptoms (e.g., hyperkinesias and paresis), but they began to maintain their head, sit, and stand later than age-related norms. They also formed locomotor functions later, including climbing, walking, and jumping. Psychomotor deficits in most children with speech pathology suggest an interrelation and interdependence between speech and motor development. They also indicate a functional unity between speech (not only its motor component) and motor systems during the process of forming a child's ontogenesis. The stimulation of finger movement has been shown to affect maturation of the central nervous system (Kol'tsova, 1973).

Speech deficits in children with motor underdevelopment indicate the importance of the motor system in a child's neuromental development, proving the need for specialized complex neuropsychological remediation for all components of a child's motor development.

Significant correlations were found between child's motor retardation and gnostic defects. Active hand movements (e.g., crawling and gripping a toy) stimulate the formation of constant object images and orientation in space. As mentioned above, spatial defects are observed in most children with ADHD and are aggravated in school age (Figure 3). Perseverations and uncoordinated movements can be seen, together with difficulty following programs in dynamic praxis and the immaturity of spatial functions in praxis and drawing.

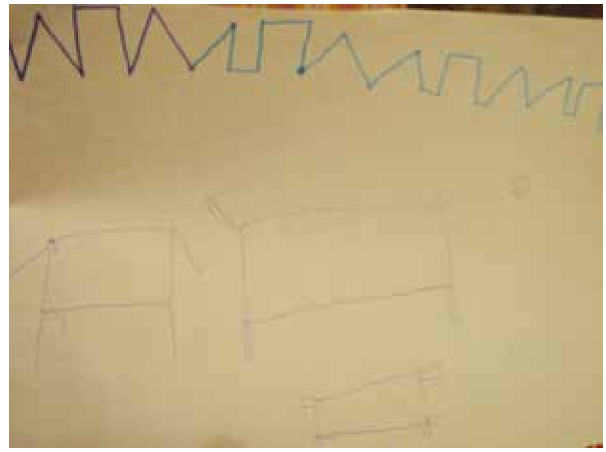

Figure 3. Example of graphic test and drawings of a table made by an 11-year-old boy with ADHD.

Remediation of ADHD

Even psychiatrists say that drugs alone do not solve the entire spectrum of problems associated with ADHD because problems related to the development of higher mental functions cannot be overcome with medications. The follow-up of children with ADHD has shown the importance of a comprehensive strategy of motor and cognitive remediation of children with this syndrome.

The development of executive function, including voluntary regulation, orientation, and the control of one's own activities, is a central focus of the neuropsychological remediation of hyperactive children with attention deficits. Remediation methods are based on two main approaches: overcoming neurodynamic problems through the saturation of the child by activity and use of external support to mediate regulatory functions (Kurdyukova et al., 2010; Glozman, 2013; Glozman et al., 2013). The scope of the present article does not permit a detailed description of these methods.

In the present study, all of the preschoolers followed a course of neuropsychological remediation. At the end of the course, a control neuropsychological follow-up was performed, showing positive dynamics (i.e., a reduction of penalty scores) in all spheres of the children's development. The most significant changes, based on Wilcoxon *t*-tests, were found in praxis ($p = .008$), gnosis ($p = .018$), memory ($p = .012$), reasoning ($p = .018$), and conditioned reactions ($p = .043$; Figure 4). Additionally, significant improvements were observed in total neuropsychological scores (i.e., the average of all spheres of the children's assessment). This indicates (*i*) the importance of a comprehensive approach to the neuropsychological remediation of children rather than the development of a separate sphere, and (*ii*) the

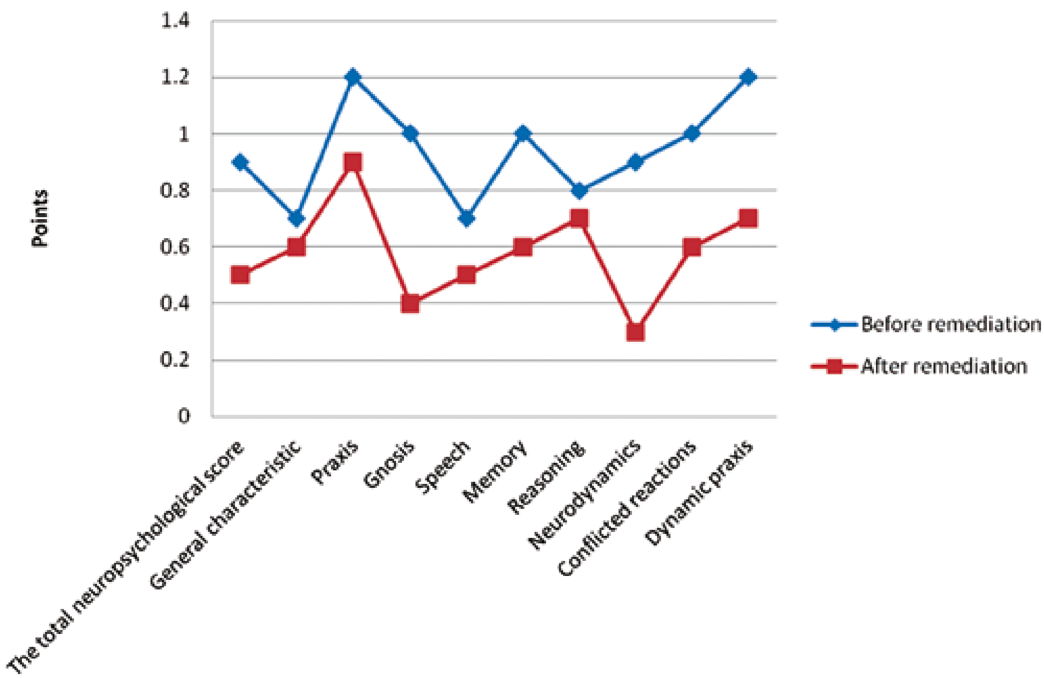

Figure 4. Dynamics of scores of preschool children with ADHD after remediation.

importance of remediation effectuated at the preschool age when there is still time before further schooling commences. The comprehensive development of all higher mental functions in a preschooler will help him become more successful in learning activities. Figure 5 illustrates the development of the spatial organization of movements and actions in a 4-year-old preschool child. Significant results already appeared after a course that consisted of 20 remediation sessions. The neuropsychological assessment of children after a remediation course showed that the methods were effective for both overcoming the problems in learning and attenuating the symptoms of ADHD [10].

Conclusions

Our experimental study revealed the complex structure of executive function disturbances in ADHD, including neurodynamic deficits, difficulty sustaining activity and attention, poor selectivity in decision making, deficits in shifting from one executed activity to another, poor planning, poor prognostic ability, problems recalling performance, and deficits in error correction. This is consistent with the published literature and complements it with important details.

Comparisons of the syndrome of ADHD between preschool and primary school children and estimation of the dynamics of mental functioning after neuropsychological remediation in preschoolers showed the importance of assessment and remediation during the early preschool stage of development. The sooner a preschooler receives comprehensive neuropsychological assistance, the easier the learning process in school.

Figure 5. The copying of simple geometric shapes (circle, triangle, and square) by a 4-year-old child with ADHD before and after remediation.

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