Life Span and Disability XXVI, 2 (2023), 165-196

Neuromotor functionality of speech readiness for school in older preschool children with logopathology

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Abstract

The purpose of this study was to identify the current state of neuromotor functionality, which affects speech readiness for schooling, in older preschool children with speech pathologies. Research methods were aimed at studying the components of neuromotor functionality: kinaesthetic and kinetic wrist, oral and articulatory praxis. Significant differences emerged in the formation of neuromotor functionality between the groups of children with logopathology and those with normotypical psychophysical development. In older preschool children with speech disorders, low abilities were found when performing tasks of

Received: October 27, 2022; *Revised:* September 4, 2023; *Accepted:* November 22, 2023

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Disclosure statement: No potential conflict of interest was reported by the author.

Ethical approval: During the collection of experimental data, the consent of the parents of the subjects participating in the study was obtained. Relevant ethical norms and rules were observed while conducting the research; no moral pressure was exerted on the children. All procedures performed with the respondents were in accordance with the ethical standards of the institutional and/or national research committee, as well as with the 1964 Declaration of Helsinki and its later amendments or corresponding ethical standards. The examination of the study was carried out by the Commission on Academic Integrity of the Ivan Ohienko Kamianets-Podilskyi National University and approved by the Department of Speech Therapy and Special Methods.

Funding: None.

Acknowledgements: The authors thank the pedagogical teams of preschool educational institutions and the parents of the children participating in the study for their cooperation.

doi: 10.57643/lsadj.2023.26.2_07

kinaesthetic and kinetic wrist (fussy movements of the fingers and hands; searching for the right position and the incorrect joining of the fingers and hand positions; the presence of perseverance of previous movements; underdeveloped fine motility of the fingers of hands; difficulties in subject activities), oral (problematic switching of organs of the articulatory apparatus; long search for an articulatory posture, incomplete range of motion, deviation from configurations, presence of synkinesis, hyperkinesis), and articulatory (defect of all sounds of groups; replacement, mixing, distortion or absence of individual sounds during their isolated pronunciation; distortion of the sound-syllable structure of words) praxis. Children were found to be passive during classes and needed constant support from the teacher. The revealed shapeless state of neuromotor functionality confirmed our hypothesis. Impairment of neuromotor function is present in a significant percentage of preschoolers with speech disorders, which becomes a characteristic feature of this category of children.

Keywords: Children of older preschool age; Wrist praxis; Oral praxis; Articulatory praxis; Speech disorder.

1. Introduction

1.1. Relevant scientific research and analysis of issues

The neuromotor functioning of speech is a complex, multifaceted process, which is ensured by cortical cells, subcortical formations, and centrifugal nerve fibers located in speech motor and sensory centers (Luria, 1982; Kokun, 2006).

Broca's motor center, which lies in the posterior-inferior part of the third frontal gyrus of the left hemisphere (next to the Penfield motor area) and performs the motor function of the muscles of the face, tongue, palate and pharynx, is important for articulating speech sounds. Its damage leads to oral speech disorders (alalia, aphasia, dysarthria, stuttering) – i.e. to the inability to combine individual sounds, syllables, and words into a single speech act (Clerget, Badets, Duqué, & Olivier, 2011; Long, Katlowitz, & Svirsky, 2016; Lorca-Puls, Gajardo-Vidal, Ploras, Oberhuber, Prejawa, Hope *et al*., 2021). The *Penfield center* is responsible for the kinetic and kinaesthetic motor-sensitive organization of speech. The motor (efferent/kinetic) articulation area lies in the anterior central gyrus and switches the articulatory positions. The sensory (afferent/kinaesthetic) articulation zone lies in the posterior central gyrus and ensures the maintenance of the articulation position. Damage to this centre leads to disorders of static and dynamic movements of the articulatory apparatus (Kokun, 2006).

It should be noted that the full functioning of speech is equally affected. *Wernicke's center* (speech and auditory) lies in the posterior part of the upper temporal gyrus of the left hemisphere. It provides the phonemic analysis and synthesis of sound symbols of oral speech. Damage to this area causes impaired word perception (sensory aphasia) (DeWitt & Rauschecker, 2013). *Degerin's center* (writing and reading control) is positioned in the left hemisphere in the area of the angular gyrus of the dominant hemisphere. Its lesion results in verbal blindness (alexia or sensory aphasia), namely, the lack of understanding written speech. *Subcortical nodes* are responsible for the pace and expressiveness of speech, while *cranial nerve nuclei* (*CN V* − trigeminal, *CN VII* − facial, *CN IX* − glossopharyngeal, *CN X* − vagus, *CN XI* − accessory, *CN XII* − hypoglossal) provide sensitivity and mobility of the articulation organs. As we can see, there is no single center of speech, but it is formed by the speech cytoarchitectonic fields of the cerebral cortex (Luria, 1982; Guenther, 2006; Long *et al*., 2016).

Speech readiness for school requires a sufficient level of neuromotor functioning of the hand, oral and articulatory praxes. Neurophysiological studies (Roby-Brami, Hermsdörfer, Roy, & Jacobs, 2012) show that praxis (Greek: praxis − action) is a system of voluntary, purposeful motor actions that provide practical skills for various activities. Motor control and movement control are organized by the frontal lobe of the premotor cortex. The activity of the latter involves the sequential synthesis of individual motor impulses into unified “kinetic structures” that are automated during training and provide a dynamic process of complex movements and motor skills. Luria (1982) divided all praxis actions into two types of praxis: kinesthetic praxis (afferent) is sensory and provides an understanding of one's own body. The information gathered from the senses (from sensory neurons) is converted into nerve impulses and reaches the central parts of the brain via afferent pathways, in particular, the parietal lobe of the left hemisphere; kinetic praxis (efferent) carries out motor activity. Electrical impulses are spread from the premotor area of the frontal lobe cortex, which activates the muscular, tendon and joint systems.

The interdependence between speech components and gestures has been thoroughly studied and explained from both neurophysiological and psycholinguistic perspectives (Luria, 1982; Saltzman & Munhall, 1989; McNeill, 1998; Amiel-Tison, 2001; Wang, Lekhal, Aarø, & Schjølberg, 2014; Oberer, Gashaj, & Roebers, 2017; Cadoret, Bigras, Duval, Lemay, Tremblay, & Lemire, 2018; Sansavini, Favilla, Guasti, Marini, Millepiedi, Di Martino *et al.*, 2021). Scientific research convincingly proves that not only cognitive processes, but also kinetic and kinesthetic *hand praxis*, affect the coordinated mechanism of speech. In her study, McNeill (1998) argues that the development of speech is interconnected with gestures. The ontogeny of speech at an early age begins with gestural activity, which at the age of three or four, turns into a gestural-speech unity through the self-regulation of movements. This stage of development is called “Mead's Loop”, i.e., a change that takes place in a certain psychological and linguistic environment during the formation of speech. The prefrontal cortex, which connects the ring of speech centers in the brain, is undergoing maturation during this period and may be an additional factor in the late maturity of speech components (McNeill, 1998).

The unity of speech movements and gestures has an internally conditional mechanism (Gafos & van Lieshout, 2020). Speech systems interact with motor activity; more specifically, phonological grammar models gestures and regulates acceptable symbolic combinations; the content (parts of words) of lexical realization can be conveyed through speech gestures; the acoustic realization of sound depends on the development of the articulatory motor function (Goldstein, 2019).

Developed fine motor skills of the fingers contribute to the acquisition of oral (Oberer *et al.*, 2017) and written language skills (Van der Fels, Te Wierike, Hartman, Elferink-Gemser, Smith, & Visscher, 2015; Cameron, Cottone, Murrah, & Grissmer, 2016) and determine overall psychophysical maturity (Luria, 1982; Bielova, 2022). Motor finger activity via kinesthetic impulses innervates the speech centers (in particular the Broca center), affecting their functional capabilities. Insufficiently developed subjective activity of hand praxis in older preschool children may indicate the shapelessness of their speech functions.

The motor activity of the organs of the articulatory apparatus is provided by *oral praxis*, the actions of which are considered more complex than hand praxis, as they are formed on abstract concepts (puffing up the cheeks, frowning, clicking the tongue, stretching the lips into a tube, etc.). Differential articulatory movements of the facial muscles, lips, tongue, and oral cavity are performed by oral kinesthetic praxis. Oral kinetic praxis activates the actions of the articulation organs (tongue − lips, jaws − tongue, jaws − lips). Well-formed oral skills in a child are a prerequisite for a correct sound pronunciation (an act of articulatory praxis) (Pakhomova, 2013; Pylyaeva, 2021).

Articulatory praxis is the ability to pronounce sounds and form an articulatory posture in accordance with the sound of speech (Luria, 1982). It should be emphasized that kinesthetic (afferent) articulatory praxis is responsible for the reproduction of isolated speech sounds and the creation of articulatory positions (articulums). The combination of sounds into syllables and words is provided by kinetic (efferent) articulatory praxis.

Praxis disorders lead to apraxia. Different forms are caused by the damage to certain areas of the left hemisphere cerebral cortex, namely by lesions of the parietal region that disrupt static (kinesthetic) movements of the hand, oral and articulatory systems; frontotemporal damage affects the dynamism (kinetic) of movements, causing their slowing down, inability to switch from one position to another, and perseverances; damage to the parieto-occipital lobe of the brain affects specific spatial orientation (Hill, 1998; Wang *et al.*, 2014; Park, 2017).

Special psychological and neurophysiological studies reveal a specific relationship between speech and motor skills of children with special educational needs (Van Lieshout, Bose, Square, & Steele, 2007; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013; Leonard, Bedford, Charman, Elsabbagh, Johnson, Hill *et al.*, 2014). Children with speech and language impairments replace words with gestures during communication, although their fine and gross motor skills are quite low and do not correspond to normotypical development (Iverson & Braddock, 2011); gross and fine motor skills are interconnected with speech mechanisms (Gonzalez, Alvarez, & Nelson, 2019; Alcock & Connor, 2021). Speech and language impairments are more pronounced and have a greater impact on the motor organization (Visscher, Houwen, Scherder, Moolenaar, & Hartman, 2007). In addition to the underdevelopment of speech and motor functions, this category of children is characterized by underdevelopment of cognitive processes (Flapper & Schoemaker, 2013) and problems in hand-eye coordination (Kulp, Ciner, & Maguire, 2017; Varuzza, D'Aiello, Lazzaro, Quarin, De Rose, Bergonzini *et al.*, 2023).

The above-mentioned research, although valuable, is narrowly focused. The reports published thus far do not sufficiently reveal the relationship between speech mechanisms and motor functions in children with different specific speech development disorders (dyslalia, stuttering, rhinolalia, dysarthria).

1.2. Research hypothesis

Based on the literature published (Luria, 1982; Wang *et al.*, 2014; Cameron *et al.*, 2016; Long *et al.*, 2016; Park, 2017; Goldstein, 2019; Gafos & van Lieshout, 2020), we can assume that the lack of neuromotor functionality of the wrist, oral and articulation praxis is present in a significant percentage of preschoolers with speech disorders. And this becomes a characteristic feature of this category of children.

The purpose of the article was thus to identify the current state of neuromotor functionality affecting the speech readiness to study at school in older preschool children with speech pathologies.

To achieve the set goal, the following were taken into account: i) consider the issue of the impact of neuromotor functionality on the speech readiness of older preschool children to study at school; ii) outline the types of techniques for the complex diagnosis of neuromotor functionality of speech readiness, and iii) reveal the state of formation of neuromotor functionality of older preschool children with normotypical psychophysical development vs logopathology.

2. Methods

2.1. Design

We considered the neuromotor functionality of speech readiness through the wrist, oral, and articulatory praxis. The kinaesthetic praxis of the studied components should determine the child's ability to perform certain differentiated movements (fingers, organs of articulation, pronounce isolated speech sounds) and to exercise control over them. Kinetic praxis indicates the preschooler's ability to combine various movements into a coherent action by performing a certain activity with the fingers, by switching the organs of articulation from one position to another and by pronouncing sounds in syllables, words, and phrases. The results of the study of children with logopathology were compared with the indicators of their peers with normotypical psychophysical development.

2.2. Participants

The study included 607 older preschool children (5-6 years old), of which 250 had normotypical psychophysical development and 357 had logopathology (dyslalia, $n = 212$), stuttering ($n = 40$), rhinolalia ($n = 28$) and dysarthria ($n = 77$).

2.3. Instruments

We studied the state of formation of neuromotor functionality using methods aimed at studying kinaesthetic and kinetic wrist praxis (Luria, 1982; Amiel-Tison, 2001), kinaesthetic and kinetic oral praxis (Konopliasta, 2020) and kinaesthetic and kinetic articulatory praxis (Blinova, 2001; Maliarchuk, 2003).

The evaluation criteria are defined as follows:

- wrist praxis: independent performance of the task; correct reproduction of the position of the fingers; quick rearrangement of fingers to another sample; correct reproduction of the hand position; quick transition from one movement to another; correct reproduction of the mosaic pattern; exact copying of a graphic drawing; fast stringing of a necklace;
- oral praxis: independent performance of the task; accuracy of reproduction of the articulation positions of the lips; accuracy of

reproduction of the articulation positions of the tongue; the speed of switching from the articulation position of the lips to the position of the tongue and vice versa;
- articulation praxis: independent performance of the task; correct reproduction of each group of sounds; correct reproduction of words according to their reading by the teacher (see Tab. 1 for more details).

Table 1 – *Research methods of neuromotor functionality*

The content of the neuromotor component	Methods	Evaluation criteria	General number points
Wrist praxis	Luria, 1982; Amiel-Tison, 2001	kinesthetic praxis: - fine motor skills of the fingers - kinetic praxis: - differentiated hand movements - performance of actions with objects	6
Oral praxis	Konopliasta, 2020;	kinesthetic praxis: - static position of articulation organs (tongue or lips) - kinetic praxis: - dynamic articulatory switching from one movement to another (tongue-lips, jaws-tongue, jaws-lips)	6
Articulatory praxis	Blinova, 2001; Maliarchuk, 2003	kinesthetic praxis: - pronunciation of sounds - kinetic praxis: - pronunciation of the sound-syllable structure of the word	21
		Total points	33

2.4. Procedure

To study wrist kinaesthetic praxis, we used the task – *"Fine motility of fingers"*. In this task, the child was shown different positions of the fingers and asked to reproduce them, first with the right hand, then with the left. The following positions were proposed: 1) connect the thumb and forefinger into a ring; 2) make a fist; 3) extend the index and middle finger forwards; 4) make a fist; 5) extend the index and little finger forwards. The duration of the task was set up to 2 minutes.

Wrist kinetic praxis was studied using the task *“Differentiated movements of the hand”*. The child was shown different positions of the hands and asked to reproduce them: I – simultaneous performance of different movements with two hands: 1) the fingers of the right hand are tightly clenched into a fist, the fingers of the left hand are gathered and extended forwards, the palm is turned downwards; 2) changing hand positions; II − sequential execution of various movements with one hand (first with the right and then with the left hand): 1) the hand is clenched into a fist; 2) the hand is open and turned with the “rib” down; 3) the hand hits the table with the open palm down. The duration of the task was set up to 2 minutes.

Moreover, we studied the formation of object-kinetic praxis using the task *“Performing actions with objects”*. The child was asked to perform various manipulations with objects: 1) make a mosaic pattern according to the proposed sample; 2) copy a graphic drawing; 3) string a necklace. 5 minutes were set for each group of tasks.

The results of wrist praxis were assessed by applying the following scores: 2 points - the child performed all tasks correctly; 1 point – the child needed to be stimulated, he/she made one or two mistakes; 0 points – the child made more than two mistakes. The maximum number of points for three tasks was 6 points.

To study oral kinaesthetic praxis, we used the task aimed at *“Diagnosis of articulatory motility”*. The experimenter demonstrated certain articulation positions of the lips and tongue and asked the child to repeat them, holding the organs of articulation in the desired position for 3 to 5 seconds. In the process of performing the task, attention was paid to the pace, accuracy, symmetry, and presence of synkinesis (accompanying involuntary movements).

To study oral kinetic praxis, we chose the task aimed at *“Diagnostics of articulatory switching from one movement to another.”* An adult demonstrated alternating switching from one articulation position to another and asked the child to repeat the movements. During the task, the child kept the organs of articulation in the right position and performed exercises from 4 to 5 times.

We evaluated the results of the task on a three-point scale: 3 points – each task was completed correctly; 2 points – slow and intense performance; 1 point – execution with errors (long search for a pose, incomplete range of motion, deviations regarding configuration, synkinesis, hyperkinesis); 0

points – task not completed. The maximum number of points for two tasks was 6 points.

To study articulatory kinaesthetic praxis we presented children to the task – *"Diagnostics of sound speech"*. Preschoolers were offered to independently name the depicted objects in the pictures, where the sound was reproduced at the beginning, middle and end of the word. If the child did not cope with the task, he/she was asked to repeat the same words according to the speech therapist (in the reflected pronunciation). To evaluate the results of the task, all sounds were conditionally divided into six groups: I − whistles − [z], [ts], [s], [z′], [ts′], [s′], [dz], [dz′]; II − sibilants − [h], [h], [sh], [sh], [j]; III – sonorous – [r], [r′]; IV – sonorous – [l], [l′]; V – iotaed sound combinations; VI − all other sounds. Each group was evaluated separately: 3 points – the child correctly reproduced all groups of sounds; 2 points – one or more sounds were not automated; 1 point – distorted pronunciation of sounds or their replacement with other speech sounds (for example, [r′] was the correct pronunciation, and [r] was defective); 0 points − all sounds or several of the group were defective. The highest number of points for one group of sounds was 3 points. Considering all groups, the total number of points was 18.

To study kinetic articulatory praxis, we used the task *"Diagnostics of the sound-syllabic structure of the word"*. The experimenter read to the child words that were complicated in terms of their constituent structure and asked him/her to repeat them. The following scores were assigned to evaluate the results of the task: 3 points – correct reproduction of words according to their reading by the teacher; 2 points – slowed-down syllabic reproduction; 1 point – distortion of the sound-syllable structure (pauses, rearrangement of syllables); 0 points − failure to complete the task. The maximum number of points for the two methods studying articulatory praxis was 21 points.

The total score for the three components of neuromotor function (wrist praxis – 6 points, oral praxis – 6 points, articulatory praxis – 21) was 33 points.

Experimental research included the variational-statistical (quantitative) and the qualitative analysis of study material (Miles & Huberman, 2000; Palka, 2006; Yahela, 2015), which allowed to understand the structure of the studied phenomenon, its variability, dependence, relationship and principles of functioning. An important component of the psychological and pedagogical experiment was also the collection and processing of research material. The implementation of this stage was ensured by the formed system of evaluation criteria (based on point measurement). Quantitative and statistical analysis provided grounds for identifying the levels (i.e. low, medium and high) of development of the phenomenon under study. The qualitative analysis considered a holistic approach focused on an inductive description of the unit under study. Variational-statistical and qualitative analyzes of the research data during the study of the cognitive component of speech readiness of older preschool children with logopathology to be studied at school provided the basis for carrying out a psychological-pedagogical characterization and generalized conclusions regarding the planning of educational and work developmental activities.

Differences in the research results (while performing experimental tasks) between children with logopathology and those with normotypical development were confirmed by the Student's parametric t-criteria. To check the data, we used the *t*-criteria of an independent sample. During the statistical analysis, we worked out two hypotheses: H_0 – the differences between the groups of children with logopathology and normotypical development were random; H_1 – the differences between groups were significant or reliably significant. If t_{em} statistical < t_{tab} tabular we accepted hypothesis H_0, if t_{em} statistical ≥ t_{tab} tabular we accepted hypothesis H_1. The level of confidence (or error) was set at $p = .05$, indicating the reliability of the results of the experiment by 95%.

3. Results

3.1. Wrist praxis

To study the formation of hand kinaesthetic praxis, we turned to neurophysiological methods, which allowed us to study the ability of children to correctly reproduce different positions of the fingers of the hands according to the model: first with the right hand, then with the left. The results showed that a high level of finger praxis was recorded in 85.6% ($n = 214$) of preschoolers with normotypical development and 45.9% ($n = 164$) with logopathology. The results of this group of children indicated the ability to reproduce the given positions of the fingers independently and correctly, which was descriptive of a sufficiently formed level of fine motor skills.

Older preschoolers who made minor mistakes during the task and sometimes needed stimulating help from the teacher had an average level of formation of kinaesthetic finger praxis. This was mostly observed in children with logopathology (33.1%, $n = 118$) than in children with normotypical development (14.4%, *n* = 36). The children were asked to quickly complete the task by choosing the right position of the fingers, so they often made mistakes: for example, when asked to connect the thumb and index fingers in a ring, they simply connected the thumb and the index fingers, or had difficulty in transitioning from clenched fingers into a fist to a position where the index finger and little finger were stretched forwards. Inattention led to an increased number of attempts and need of help from an adult.

A low level was observed in 21% (*n* = 75) of children with logopathology, who made more than two errors and needed the constant support from the teacher. But this level was most characteristic of children with dysarthria (45.5%, *n* = 214), who have weakly developed finger praxis; with a neurotic form of stuttering (15%, *n* = 6), in which we noted the lack of fine motor skills, the need for additional instruction and for a visual sample was vital. Preschoolers of this group did not pay attention to their motor errors, all attempts to complete the task had limitations. For example, we observed: a long search for the position of joining the thumb and index fingers into a ring (they connected different fingers); difficulty in moving from the position of clenched fingers into a fist to the position where the index and little fingers were stretched forwards (they extended different fingers forwards); difficulty in switching from the right hand to the left; difficulty in obtaining the built position of the fingers with the teacher's sample; the need for approval and encouragement from an adult to complete a task correctly. Slowness, the increased number of attempts to execute the tasks, the inconsistency of motor actions and the need of adult help indicated insufficient attention. The reduced ability for motor activity of finger kinaesthetic praxis gives reasons to foresee problems during mastery of motor skills of written speech.

As already described, to study kinetic praxis, we used the task *“Differentiated movements of the hand “* (refer to Methods section for more details). The child was thus asked to perform different movements with two hands at the same time and successively perform different movements with one hand only (first with the right, then with the left). As expected, high scores in this task were obtained mostly by children with normotypical development (49.6%, *n* = 124) than with logopathology (31.4%, *n* = 112). These children demonstrated the ability to independently reproduce various movements according to the example of the teacher. Some of them could make mistakes, but they corrected themselves and performed the task successfully.

On average, the exercise was performed with errors in 42.9% (*n* = 153) of preschoolers with logopathology and in 40.8% (*n* = 102) of children with normotypical development. The children did not perform the task clearly and often made mistakes in changing the position of their hands; sometimes they needed the help of an adult in the additional demonstration of the task.

Insufficiently formed dynamic praxis and a detected low level were observed in 20.2% of preschoolers, 40.8% (*n* = 72) with speech disorders and 9.6% (*n* = 24) with normotypical development. This group of children had significant difficulties during the task. It was difficult for them to perform different movements with two hands at the same time: the right hand to be clenched into a fist, the left hand to be turned downwards with an open palm (i.e. they had confusion of the hands, a non-dynamic performance), or the opposite, the left hand to be clenched into a fist, the right hand to be turned downwards with an open palm (i.e. they showed difficulties when switching to different movement positions). Equally difficult was the sequential execution of various movements with one hand: in this case, the hand was to be clenched into a fist, then opened with the "rib" down, followed by hitting the table with the open palm down; the children showed an inhibited reorientation of the movement from one position to another. Significant problems in the development of dynamic praxis were observed in children with dysarthria and stuttering, who quickly got tired of the task; their movements were not rhythmic, there were difficulties when switching from one position to another, and they needed stimulating help from the teacher more than other peers.

Older preschool children were asked to perform actions with various objects while teaching them a mosaic pattern according to the proposed sample: the image of a graphic picture or stringing a necklace. High indicators were demonstrated by 88% (*n* = 220) of children with normotypical psychophysical development and 45.9% (*n* = 164) with logopathology. Preschoolers correctly assembled mosaic patterns according to the proposed sample, i.e. they were able to graphically represent the drawing and to string a necklace on a thread without the help of an adult. Some could make mistakes during the task but corrected themselves independently.

Minor difficulties arose in the second group of children, who had an average level of subject praxis development. 33.9% (*n* = 121) of preschoolers with logopathology and 12% (*n* = 30) with typical development tried to complete the task quickly, so they often made mistakes: in the number of mosaic parts for assembling a pattern; in strokes in a graphic picture; in the number of beads. The correct performance of the task depended on the help from the teacher, who often emphasized: "Compare your work with the sample. See if everything is done correctly?". Then, the children noticed the flaws in their performance and quickly corrected themselves.

Difficulties arose in children of the third group of preschoolers; according to the research indicators, 20.2% (*n* = 72) of children with speech disorders had a low level of development of subject praxis. Preschoolers often incorrectly chose the colors or the number of mosaic parts to make a pattern; extra strokes were depicted in the graphic picture, or they were not drawn; beads were missing and tasks were not performed correctly even with the help of an adult. Rapid fatigue was observed in children with dysarthria as well as slow down in actions. Insufficiently developed fine motor skills caused difficulties in the operational actions of the fingers. For example, in holding a pencil (not adjusting the pressure of the pencil, sloppy drawing, not following the contours of the image), in stringing beads on a thread, or in collecting small mosaic parts to assemble a figure. In preschoolers with a neurotic form of stuttering, we noted unstable muscle tone, and impaired fine motility of the hands, which led to persistent errors when performing practical tasks.

The general indicators of the study proved that 214 (85.6%) older preschool children with normotypical psychophysical development and 44.8% (*n* = 160) with logopathology had a high level of wrist praxis. Children independently and correctly reproduced all positions of the fingers and hands; in most cases, they unerringly made mosaic patterns according to the proposed sample, they graphically depicted the patterns and strung a necklace on a thread. Minor difficulties in reproducing the desired position of the fingers and hands were observed in children with an average level of speech disorders (31.4%, *n* = 112) and with typical development (14.3%, *n* = 36); in these children, the smooth transition from one position to another was expressed with difficulty and the correct execution of most kinetic and practical tasks was performed by being stimulated by an adult. A low level in the execution of the task was observed only in 23.8% (*n* = 85) of children with speech disorders. In this case, preschoolers chaotically performed the movements of fingers and hands, they searched for the right position, exposed extra fingers, or connected them incorrectly; they showed the presence of perseverance of previous movements, expressed difficulties when performing tasks with objects and needed the constant help from the teacher (Tab. 2).

Table 2 – *The level of formation of hand praxis*

Speech development	Level			$M \pm SD$
	High	Average	Low	
Normotypical development	85.6	14.1	.0	5.2 ± .9
Dyslalia	61.3	21.7	17.0	4.2 ± 1.9
Stuttering	60.0	25.0	6.0	4.5 ± 2.1
Rhinolalia	21.4	50.0	28.6	3.1 ± 1.9
Dysarthria	.0	54.5	45.5	1.8 ± 1.4
Children with logopathology	44.8	31.4	23.8	3.3 ± 2.1

According to statistical analysis (Student's *t*-test), older preschoolers with logopathology ($M \pm SD$ = 3.33 ± 2.13; *SEM* = .14) developed wrist praxis insufficiently compared to students with normotypical psychophysical development ($M \pm SD$ = 5.23 ± .98; *SEM* = .09). Empirical total results (t_{em}) was 9.44. The largest deviation was observed in children with dysarthria (t_{em} = 20.31), followed by children with rhinolalia (t_{em} = 6.98), dyslalia (t_{em} = 4.69), while the smallest deviation was reported in children with stuttering (t_{em} = 3.73). The detected standard error of difference *(SED)* was .375. Considering the degrees of freedom (γ = 655), the tabular (ttab) value within p = .05 corresponded to 1.96. Empirical values were greater than theoretical ones (t_{em} 9.44) > t_{tab} 1.96). Accordingly, the H_1 hypothesis at the significance level of 5*% (p* = .05*)* was accepted and confirmed differences between the experimental groups. Therefore, in children with logopathology, hand praxis did not correspond to age development and needed additional educational and developmental influence.

3.2. Oral practice

During the study of oral kinaesthetic praxis, the child was asked to hold the organs of articulation in the desired position for three to five seconds. High indicators were shown by 71.2% (*n* = 178) of children with normotypical psychophysical development and 42.9% (*n* = 153) with speech disorders. The children carefully listened to the teacher's instructions, and independently, correctly and accurately performed the movements of the organs of the articulation apparatus.

In 46% (*n* = 145) of preschoolers with speech pathologies and in 28.8% (*n* = 72) with normotypical psychophysical development, tasks were performed with errors and self-corrections. The children performed the task correctly, but they had a slower pace and had difficulty in the execution of the positions of articulation. They often needed additional instruction or assistance. In preschool children with rhinolalia, slight violations of coordination and in the smoothness and accuracy of movements were detected; with dysarthria the muscles of the face and mouth are tense or relaxed, which affected the quality of their performance of tasks.

16.5% (*n* = 59) of children with speech pathologies had low indicators of the formation of oral praxis in which there was a violation of the coordination of articulatory motor movements; 35.7% (*n* = 10) of children with rhinolalia performed articulatory movements imprecisely and undifferentiately and the pace of the task was slowed down; 42.9% (*n* = 33) of children with dysarthria have the most pronounced violations regarding facial expression. They expressed difficulty in switching from one articulatory movement to another, in maintaining an articulatory posture, and keeping a wide tongue on the lower lip. During the exercise "brushing the upper and then the lower teeth", children moved the lower jaw together with the tongue from right to left, which determined clear violations of the verbal instructions.

Regarding the study of kinetic oral praxis, 56.0% (*n* = 156) of children with normotypical psychophysical development and 36.4% (*n* = 130) with speech disorders were able to switch from one mimic pose to a niche (tongue-lips, jaws-tongue, jaws-lips). The children performed the tasks correctly and accurately performed the movements of the organs of the articulatory apparatus.

Minor errors during the execution of the task were observed in 42.9% (*n* = 153) of preschoolers with speech disorders and only 44% (*n* = 44) with normotypical development. In this category of children, who had an average level of kinetic oral praxis, minor facial disturbances were observed during the reproduction of a series of movements and the need for help from an adult was modest.

Significant switching difficulties were found in 20.7% (*n* = 74) of children with low-level speech pathologies. During the exercises, the children could not immediately find the right pose for the organs of articulation, it was difficult for them to keep it unchanged for 5-6 seconds and there were difficulties in switching from one movement to another. The following types of disorders were found in children with dysarthria: asymmetric muscle work (protruding tongue deviated to the right or left from the middle line of the lips; shift in the direction of a smile); problematic performance of individual movements (i.e. the child's inability to reach the tip of the tongue first to one and then to the other corners of the mouth); excessive amplitude when performing movements (instead of the tongue touching the upper teeth, the tongue protruded from the mouth too much and covered the upper lips); synchronicity of the movements of the speech organs (when making movements with the tongue to the right and left, the lower jaw also moved); disturbed muscle tone (tension of the muscles of the tongue and lips; during muscle hypotonia, the tongue was limp, occupying a stationary position at the bottom of the oral cavity, the lips were not closed, the mouth was half-open and there was pronounced hypersalivation); nasalization of voice (nasal tone of voice); difficulty in switching from one articulatory movement to another, in maintaining an articulatory posture, and in keeping a wide tongue on the lower lip. Children with rhinolalia were observed to skip the sequence of articulatory movements, to rearrange them, or distort the exercise. During the performance of the task, we observed a violation of the neurological status. This was expressed by an increase in the tone of the articulatory muscles, especially the tongue and lips (the tongue was tense and drawn upwards into the oral cavity, becoming a lump), or hypotonicity, and in the vagueness of the facial expressions. Moreover, the space between the lips was noticed, the tongue was not mobile, the presence of tremor of the tip of the tongue when switching from one movement to another was observed and the soft palate was inactive. In children with a neurotic form of stuttering, there were also disorders in the facial articulation and difficulty in switching and maintaining oral “tongue-lips” postures. Most of them were not able to correct their mistakes despite the constant help from the teacher.

The general results of the research data proved that a high level of oral praxis was mostly characteristic of 71.2% (n = 178) of older preschool children with normotypical psychophysical development and 42.9% (n = 153) with logopathology. Children independently, correctly and accurately performed movements of the organs of the articulatory apparatus following imitation or verbal instructions. They expressed a kinaesthetic and kinetic praxis that was sufficiently formed. As for the former (kinaesthetic praxis), these children showed to be able of performing individual articulatory oral movements, for example, by stretching the lips in a smile, pulling the lips forwards with a tube, spreading a wide tongue forwards or raising a narrow tongue upwards, raising the lateral and front edges of the wide tongue upwards, slapping the tongue, sticking out the tongue forwards and then retracting it suddenly, and finally alternating movements of the tip of the tongue to the left and then to the right corner of the mouth. As for the latter (kinetic praxis), the children showed to be able to combine the articulatory movements of the tongue and lips by changing the positions of the tongue and the positions of the lips. An average level of oral praxis was scored by 36.7% (n = 131) of preschoolers with logopathology and by 28.8% (n = 72) of those with typical development who had both minor difficulties when reproducing the desired articulatory position. Their pace of execution was different, from fast to slow and the correct facial expression depended on the help of an adult. Finally, a low level of oral praxis was observed only in 20.4% (n = 74) of children with speech pathologies. In this case, preschoolers experienced difficulties when making movements with the organs of the articulatory apparatus and performed tasks with many errors (searching for a pose for a long time, expressing an incomplete range of motion or deviation from the configurations, and with the presence of synkinesia, hyperkinesis). They also were in constant need of the teacher's help (Tab. 3).

Table 3 – *The level of formation of oral praxis*

Speech development	Level			$M \pm SD$
	High	Average	Low	
Normotypical development	71.2	28.8	.0	5.3 ± 1.0
Dyslalia	52.0	37.7	10.3	4.8 ± 1.2
Stuttering	65.0	20.0	15.0	4.9 ± 1.4
Rhinolalia	28.6	35.7	35.7	3.8 ± 1.5
Dysarthria	11.7	42.9	45.5	3.5 ± 1.1
Children with logopathology	42.9	36.7	20.4	4.3 ± 1.4

The investigated reliability of the results of the experiment indicated that low indicators of oral praxis were expressed by children with logopathology ($M \pm SD$ = 4.29 ± 1.39; SEM = .09) compared to children with normotypical psychophysical development ($M \pm SD$ = 5.26 ± 1.05; SEM = .09). Empirical (t_{em}) data corresponded to 6.72. The largest deviation was found in children with dysarthria (t_{em} = 11.50), followed by children with rhinolalia (t_{em} = 4.70) and dyslalia (t_{em} = 2.72). Interestingly, the deviation in children with stuttering (t_{em} = 1.51) was close to normotypical development (t_{em} = .87) and was therefore considered not statistically significant. The standard error of the difference *(SED)* of the total data was .14. The empirical value for the group was greater than the theoretical value (t_{em} 6.72) > t_{tab} 1.96). Accordingly, the H_1 hypothesis at the significance level of 5% *(p = .05)* was accepted, confirming the differences between the experimental groups and the insufficient formation of oral kinaesthetic and kinetic praxis in children with logopathology.

3.3. Articulation praxis

To study kinaesthetic articulatory praxis, preschoolers were asked to independently name the depicted objects in the pictures, where the sound was at the beginning, in the middle, and at the end of the word. The results of the task showed that all children with normotypical psychophysical development and only 7.28% (n = 26) with logopathology, namely older preschoolers with stuttering, had high phonological indicators.

One or more sounds were not automated in 56% (n = 200) of children with speech pathologies, which indicated an average level of development of kinaesthetic articulatory praxis. This group of preschoolers could skip some sounds in a word and mix and distort sounds. Defects in sonority and deafening of sounds were observed, when paired unvoiced ones were replaced by sonorous ones, as well as defects in the hardness and softening of sounds. The largest number of errors in the task was made by 36.7% (n = 131) of preschoolers with complex sound-speech disorders, who had a low level of articulatory praxis since they failed to pronounce different groups of sounds.

The results of the study of kinetic articulatory praxis showed that 95.2% (n = 238) of children with normotypical psychophysical development and 16.3% (n = 58) with speech pathologies were able to correctly pronounce complicated words and had a high level of word formation. Average indicators showed that 4.8% (n = 12) of preschoolers with typical development and 58.5% (n = 209) with speech disorders reproduced words slowly and syllabically without maintaining the speech tempo and needed the stimulating help from the teacher. Only 25.2% (n = 90) with speech pathologies had a low level, i.e. distorted the sound-syllabic structure of words, made pauses, and permutations, omitted syllables, and added sounds and extra syllables. We also noted the violation of the sound content of words, which was expressed, for example, by excluding consonants from the word that was located next to each other, by adding an extra sound to the composition of the word, by the rearrangement of sounds, the repetition of a similar composition, and the violation of the syllabic rhythmicity of the word structure (i.e. reduction, permutation of syllables, the addition of extra syllables).

General indicators of articulation praxis showed that a high level was achieved in 95.2% (*n* = 238) of older preschool children with normotypical psychophysical development and 7.3% (*n* = 26) with logopathology, namely with stuttering. The children independently and correctly reproduced each group of sounds and complicated words, which indicated that they had sufficiently formed the sound-syllable structure of the word. The average level of articulatory praxis was reached by 58.8% (*n* = 210) of children with logopathology and 4.8% (*n* = 12) with typical development. In this case, one or more sounds were not automated, the distortion or replacement of one sound from the group was observed, there was the slow syllabic reproduction of words without keeping pace as well as the need for help from the teacher. A low level of development of articulatory praxis was noted in 33.9% (*n* = 121) of children with speech disorders, who had the greatest problems in phonetic speech, showed defectiveness of all or several sounds of groups, the replacement, mixing, distortion or absence of individual sounds in isolated pronunciation, the distortion of the sound-syllable structure (pauses, rearrangement, omission, addition of sounds and syllables) and the incorrect performance of the task without the help of an adult (Tab. 4).

Table 4 – *The level of formation of articulation praxis*

Speech development	Level			*M* ± *SD*
	High	Average	Low	
Normotypical development	95.2	4.8	.0	20.7 ± 1.3
Dyslalia	.0	70.7	29.3	9.1 ± 3.12
Stuttering	65.0	20.0	15.0	15.3 ± 5.5
Rhinolalia	.0	35.7	64.3	6.8 ± 3.3
Dysarthria	.0	54.5	45.5	5.3 ± 2.4
Children with logopathology	7.3	58.8	33.9	8.2 ± 4.3

Student's t-test data indicated that preschoolers with logopathology (*M* ± *SD* = 8.20 ± 4.28; *SEM* = .29) had the lowest results of articulation praxis compared to students with normotypical psychophysical development (*M* ± *SD* = 20.71 ± 1.29; *SEM* = .12). Empirical generalized data (t_{em}) scored 31.81. The largest deviation was observed in children with dysarthria (t_{em} = 58.87). It was significantly less in children with rhinolalia (t_{em} = 30.52), followed by children with dyslalia (t_{em} = 37.8), while the smallest deviation was observed in children with stuttering (t_{em} = 9.63), whose indicators were again close to normotypical development. Thus, as the empirical value was greater than the theoretical value (t_{em} 31.81) > t_{tab} 1.96), the H_1 hypothesis was at the significance level of 5% *(p* = .05*)* and confirmed the significant differences between the experimental groups.

The general level of neuromotor functionality proved that it was high (from 22 to 33 points) in 95.2% (*n* = 238) of children with normotypical psychophysical development and 35.9% (*n* = 128) with logopathology. The average level (from 11 to 21 points) was mostly observed in 42.3% of children with speech disorders and only in 4.8% (*n* = 12) of preschoolers without speech disorders. A low level (from 1 to 10 points) was instead found only in 21.8% of preschoolers (*n* = 121; see Figs 1 and 2 for more details).

Figure 1 – *The level of formation of neuromotor functionality by categories of children of older preschool age*

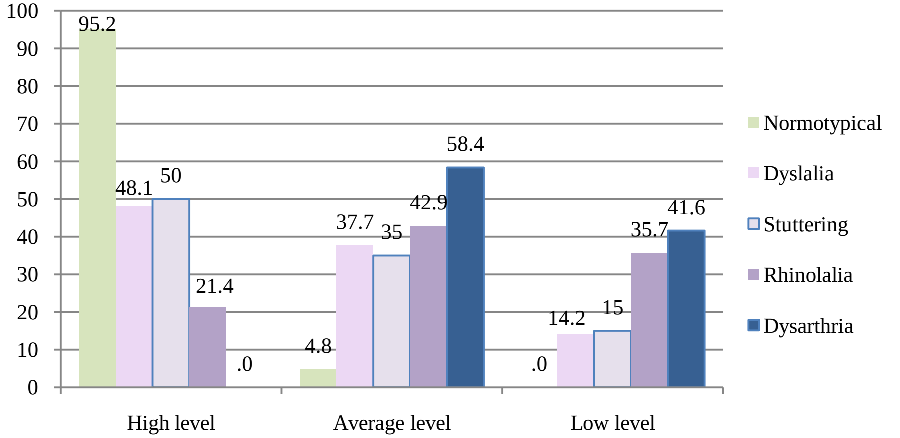
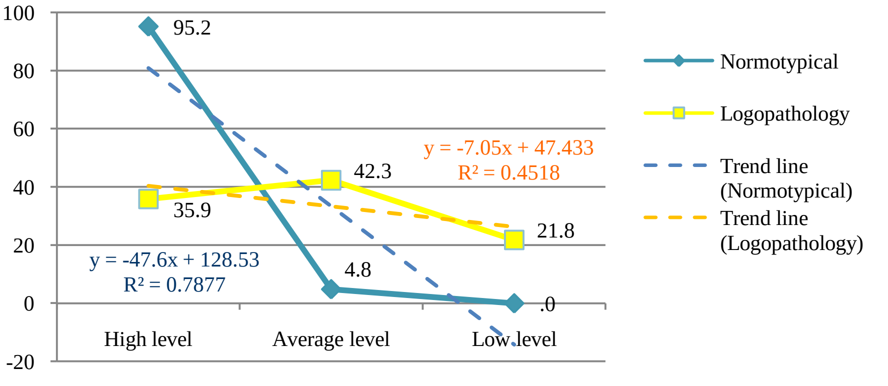


Figure 2 – *The level of formation of neuromotor functionality between normotypical children and children with logopathology*



Statistical analysis of the neuromotor function study showed that most older preschool children with logopathology ($M \pm SD$ = 15.82 ± 7.52; SEM = .51) had insufficiently formed manual, oral and articulatory praxis compared to those with normotypical psychophysical development ($M \pm SD$ = 31.20 ± 2.84; SEM = .25). Experimental data of children with speech disorders (t_{em}) was 21.95. The tabular (t_{em}) value within p = .05 corresponded to 1.96. Since the empirical results were higher than the tabular results (t_{em} 21.95 > t_{tab} 1.96), the H_1 hypothesis at the significance level of 5*% (p* = .05*)* was accepted, giving reason to assert that there were significant differences in the development of neuromotor functionality between the groups of children with logopathology and those with normotypical psychophysical development (Tab. 5).

Table 5 – *Statistical indicators of neuromotor functionality*

Field of study	Empirical value	Dyslalia	Stuttering	Rhinolalia	Dysarthria	General indicator
Wrist praxis	t_{em}	4.69	3.73	6.98	20.31	9.44
	SED	.200	.29	.31	.16	.20
	p	.01**	.03	.01**	.01**	.01**
Oral praxis	t_{em}	2.72	1.51	4.71	11.50	6.72
	SED	.14	.26	.31	.15	.14
	p	.01**	.13	.01**	.01**	.01**
Articulatory praxis	t_{em}	37.80	9.63	30.52	58.87	31.81
	SED	.31	.56	.45	.26	.39
	p	.01**	.01**	.01**	.01**	.01**
Table value *(p* = .05)	γ	460	288	276	325	605
	t_{tab}	1.96	1.96	1.96	1.96	1.96
General indicator of neuromotor functionality	Empirical indicators: t_{em} = 21,95 Standard error of the difference: *SED* = .70 Statistical significance: *p* < 01** (*p* = .05) Tabular indicators: (*p* = .05) = 1.96 Deviation (*p* = .05): $t_{em} > t_{tab}$ = 21.95 > 1.96					

4. Discussion

As reported in the literature (Sobotovych, 2015; Gafos & van Lieshout, 2020; Konopliasta, 2020), the lack of neuromotor functionality in older preschool children with logopathology delays the development of speech, namely the phonetic, lexical and grammatical levels. The harmonious functioning and production of speech are impossible without the development of motor skills (Gafos & van Lieshout, 2020). The modulation of articulatory movement and variable acoustics has the form of a pulse structure, which is related to the structure of the syllable. The pulses are aligned with each other in time, and the modulation functions have been shown to be reliably correlated (Goldstein, 2019). The phonological coordination of movements is a roughly controlled process (Saltzman & Munhall, 1989; Schaal, Mohajerian, Ijspeert, Cisek, Drew, & Kalaska, 2007; Ijspeert, Nakanishi, Hoffmann, Pastor, & Schaal, 2013; Turk & Shattuck-Hufnagel, 2020). Given that articulatory movements cause acoustic signals, disorders of articulatory (kinesthetic and kinetic) praxis lead to specific defects in speech sounds, which was confirmed by our study. As the literature suggests (Sobotovych, 2015; Konopliasta, 2020), older preschoolers with complex speech disorders show unformed static and dynamic movements of the facial muscles and are unable to hold articulatory positions during the pronunciation of sounds. Accordingly, the speech of these respondents differs significantly from the indicators of normotypical development.

The motor organization of speech and phonological control is not natural, and the modulation process is often influenced by individual characteristics, cognitive development, and other factors (Patri, Diard, & Perrier, 2019). This was also highlighted in our study, which revealed different levels (low, medium and high) of hand, oral and articulatory praxis. More in general, our study revealed that children who had a long-term psycholinguistic and correctional development were in line with the performance of normotypical children, who scored a high level. This category included children with dyslalia, stuttering and less with rhinolalia. Those who had difficulties in manipulating and controlling movements had medium and low scores. They were characterized by complex speech disorders and specific psychophysical development, which was observed in a significant percentage of children with dysarthria, stuttering (neurosis-like form) and rhinolalia.

In modern education, learning and the education of preschool children with special educational needs has become a priority issue. But, today, correctional programs and methods developed based on the State's basic component of preschool education are morally anachronistic and require a modernized rethinking and corresponding renewal. Educators, speech therapists, and correctional pedagogues need to be offered new constructive developmental programs for children with speech pathologies, where “speech readiness” for schooling should be a priority. This necessity is determined by certain statistical indicators, both in Ukraine and in other countries, which is indicated by the annual increase of children with various psychophysical disorders, as well as speech disorders (Leonard *et al.*, 2014; Sobotovych, 2015; Tyshchenko, 2021; Konopliasta & Bielova, 2022). This problem has not been solved to date and may become worse in the future, as indicated by our research data.

From a neurophysiological point of view, speech is a component of higher mental functions, it carries out the arbitrary mediation of mental processes, and links and organizes them (Jongbloed-Pereboom, Janssen, Steenbergen, & Nijhuis-van der Sanden, 2012; Endress & Bonatti, 2016; Cadoret *et al.,* 2018; Henin, Turk-Browne, Friedman, Liu, Dugan, Flinker *et al.,* 2021). Insufficiently formed speech in children with logopathology indicates problems in the development mental sphere (cognitive, motivational and emotional; Konopliasta, 2020; Bielova, 2021), which builds a promising vector for further scientific research. The experimentally revealed unformed state of the neuromotor functionality in older preschoolers with logopathology provides the ground knowledge for the introduction of modern educational and developmental methods, which would allow the formation of kinaesthetic and kinetic hand (development of fine motility of the fingers), oral (dynamic organization of facial and tongue facial muscles) and articulatory praxis (automation and introduction into the speech of all groups of sounds, work on the pronunciation of words complicated by the compound structure).

This will contribute to increasing the level of neuromotor development of older preschool children and, in the future, in their comfortable integration into the conditions of general education.

5. Conclusions

Analysis of the research results and statistical confirmation provides an opportunity for the following conclusions. A significant percentage of older preschool children with logopathology were shown to have an insufficiently formed state of neuromotor functionality, of the cognitive component as well as psychological component of speech readiness. As suggested by our study, *wrist kinaesthetic praxis* in preschoolers with logopathology was not sufficiently formed. These children had difficulty in: performing according to the model of certain finger positions (joining of different fingers), switching from one finger position to another, switching from the right hand to the left, completing tasks quickly. *Wrist kinetic praxis* in preschoolers with speech pathology was also not formed, especially in children with dysarthria and some with stuttering. These children showed difficulties during the simultaneous execution of various movements with two hands (confusion of hands, impaired performance dynamics) and showed problematic or inhibited switching from one motor position to another. Subject praxis of preschoolers with speech disorders (in most children with dysarthria and some with stuttering) developed slowly. In this group of older preschoolers, fine motor skills were not sufficiently developed and there were difficulties in the operational actions of the fingers: for example, holding a pencil while drawing graphic drawings, stringing beads on a thread, and collecting small mosaic parts to assemble a figure. *Oral kinaesthetic praxis* was mostly not formed in children with logopathology, especially with dysarthria. These children had difficulties in transitioning from one oral posture to another and in maintaining an oral posture (tongue or lip position). *Oral kinetic praxis* in preschoolers with speech disorders was underdeveloped. In fact, these children had difficulty in dynamically switching from one oral posture to another and in maintaining them. Moreover, they also performed poorly in the rearrangement of a series of elements, in their distortion or failure to complete the task and were also subject to the perseverative repetitions of the same element. *Articulatory kinaesthetic praxis* revealed to be a weak point in the neuromotor functional development of children with logopathology: the pronunciation of all groups of sounds was impaired: I – whistling; II –hissing; III, IV – sonorous; V – iotated sound combinations; VI – all other sounds. Moreover, these children also had difficulty in expressing the replacement, mixing, distortion or absence of individual sounds when they were pronounced in isolation. *Articulatory kinetic praxis* in children with logopathology indicated a distorted pronunciation of the sound-syllabic structure of the word through pauses, permutations, omissions, and addition of sounds and syllables.

It is important to underline that the speech process is implemented with the help of coordinated articulatory movements, which act as a control unit. It is worth noting that currently none of the existing theories take into account all the properties of these movements. An understanding of the principles that apply to speech movements is also fundamental to define the concept of motor speech ability, as well as to assess and interpret the different levels of such ability in populations with and without language impairment. Therefore, it is important to deepen not only the understanding of the motor aspects, but also the nature of the verbal processes and related cognitive functions of control and support (Sansavini *et al.*, 2021).

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