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Diagnosis and Correction of Auditory Perception in Children Aged 8 to 10 with Mental Retardation

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Abstract: **Introduction**. The article is devoted to identifying the features of auditory perception using neuropsychological and instrumental methods in children 8–10 years of age with mental retardation. The relevance of the work lies in the need to develop approaches to improve the learning ability of children with mental retardation. The novelty of the study lies in the evaluation of the effectiveness of psycho-corrective measures carried out using the methods of integrated impact on sensory perception in children with mental retardation. **Methods**. The study included 8–10-year-olds with no history of hearing impairment: control group (n = 34) and children with intellectual disability (n = 36). Children with mental retardation were divided into 2 subgroups, in one of which corrective work was carried out for 6 months using methods of integrated impact on sensory perception. All children were examined twice using tonal audiometry methods, recording long-latency auditory evoked potentials, neuropsychological testing. **Results**. During repeated examination (after corrective measures) in children with mental retardation, a decrease in the thresholds of tonal audiometry, as well as latency of individual peaks of long-latency auditory evoked potentials was established, which correlated with an increase in the efficiency of neuropsychological tests. In the subgroup of children with mental retardation with whom no corrective work was carried out, as well as in the control group, no changes in the studied indicators were detected. **Discussion**. In conclusion, it is concluded that the use of techniques aimed at the development of polysensory perception in children with mental retardation contributes to the improvement of auditory gnosis.

Keywords: auditory perception, children 8–10 years old, mental retardation, neuropsychological examination, audiological examination, neurophysiological examination, polysensory perception, auditory evoked potentials, Wechsler test, tone threshold audiometry

Highlights:

- The results of diagnosing auditory gnosis in children of primary school age with mental retardation

can be considered as a basis for corrective measures using pedagogical technologies aimed at developing polysensory perception.
➢ The basis of impaired auditory perception in children with mental retardation is the delay in the functional maturation of the structures of the left hemisphere of the brain.
➢ The use of correctional work methods aimed at developing polysensory perception in children with mental retardation contributes to the improvement of auditory gnosis.

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Introduction

Specific learning disorders are characteristic of all children with intellectual disability but can also occur in children with a normal level of intellectual development (Dawes & Bishop, 2010). These learning disorders are due to perceptual characteristics, which leads to impaired understanding of oral and written speech (Kolodyazhnaya et al., 2020), for example, to the occurrence of comorbid dyslexia (Banai & Ahissar, 2006; Iliadou et al., 2009).

There are various factors that determine the complexity of assessing the causes of specific learning disorders. These factors include changes in eye movements during reading, impaired information processing (visual, auditory, etc.), as well as concomitant disorders associated with attention deficit and/or hyperactivity (Cunha et al., 2019).

Of significant interest among these factors are auditory information processing disorders. In normal peripheral hearing, difficulties in localizing sounds, disturbances in recognition of auditory patterns under conditions of presenting competing auditory signals are designated as a central disturbance in sound processing (Katz, 1992). As a result of the central disturbance of auditory information processing, acoustic reflexes may be changed or absent against the background of a normally formed basic audiological signal assessment (Engelmannn & da Costa Ferreira, 2009).

Currently, it has been proposed to assess the degree of auditory impairment using various tests for binaural hearing, dichotic listening, temporary processing of auditory signals, auditory perception against the background of interference signals, as well as the perception of the acoustic structure of speech of low redundancy (constituting the phonetic structure of speech) (Bellis, 2011).

Long-latency auditory evoked potentials are recorded in the period from 50 ms to 400 ms and are due to the activity of the primary and secondary auditory cortex, and the P1, N2, P2 components are associated with the process of auditory stimulus perception, the N2 component is associated with the correct recognition of the auditory stimulus, including correlation with the memory image, P3 – with decision (Samkova, 2014; Emelina et al., 2019). Studies using the technique of recording long-latency auditory potentials have shown that children and adolescents with Down syndrome, in comparison with the control group, have longer latent periods of the main peaks, with no significant differences in amplitude (Gregory et al., 2018). In Williams syndrome, a longer latency was also found, as well as a reduced amplitude of the P1, N1, N2 and P3 components (Fagundes Silva et al., 2021).

Most of the papers focus on research on impaired auditory perception in specific learning disorders in individuals with preserved intelligence (Miller & Wagstaff, 2011; Lachmann et al., 2012; Yoshimura et al., 2021). Intelligence assessment, as a rule, is carried out using adapted versions of the D. Wexler test, while it is important to strictly follow the instructions for each subtest (Vorobyeva & Druzhinin, 1997). The relevance of studying the features of auditory perception in children with mental retardation is determined by the fact that other executive functions suffer from them simultaneously with impaired verbal function. Children with intellectual disability perform unsatisfactory nonverbal tests and tasks, have reduced cognitive interest and desire for communication, and are not active in the use of gestures and in maintaining games (Knoth et al., 2018). And since there is an idea that the skills of central auditory processing develop mainly before the age of 10–12 years (Katz, 1992), the diagnosis of auditory gnosis in younger students with mental retardation can become a fundamental diagnostic tool, as well as the basis for corrective measures using technologies aimed at developing polysensory perception and reducing disorders of speech development and learning in these children (Senkal & Muhtar, 2021). It is known that long-term use of music lessons improves speech understanding against the background of noise, improves the connection between the auditory and motor brain systems (Zendel, 2022). The most well-known method of polysensory perception development at present is sensory integration (Ayres, 2017; Kiesling, 2018). We suggest that its use in working with children with intellectual disability will contribute to the improvement of their auditory gnosis, which is based on a decrease in disorders of peripheral and/or central auditory perception.

Based on the content of the research hypothesis, *the purpose of this study* was to identify the features of auditory perception using neuropsychological and instrumental methods in children of 10–12 years of age with mental retardation, as well as to assess the effectiveness of psychocorrection measures carried out using methods of integrated impact on sensory perception.

Methods

82 children of 8–10 years of age took part in the cross-sectional study, of which 48 students at a specialized (correctional) boarding school for mentally retarded children; the control group consisted of 34 schoolchildren from secondary schools (Rostov-on-Don, Russia). In accordance with the Helsinki Declaration of the World Medical Association, “Ethical Principles of Scientific Medical Research with Human Participation” (as amended in 2000), as well as the “Rules of Clinical Practice in the Russian Federation”, all studies were conducted with the informed consent of the legal representatives of the examined children (approved by Order of the Ministry of Health of Russia dated June 19, 2003, No 266). Only children without a history of reduced/hearing loss, metabolic, cardiovascular, respiratory and infectious diseases were included in the examination. After the first audiological assessment, 12 children with intellectual disability were excluded from the examination due to misunderstanding of the meaning of the task. Thus, the baseline sample was 18 boys (mean age 8.76 ± 0.56) and 16 girls (mean age 8.39 ± 0.67) of the control group, as well as 19 boys (mean age 8.92 ± 0.39) and 17 girls (mean age 8.89 ± 0.42) with intellectual disability. The level of verbal and non-verbal intelligence in the examined children was assessed using the Wexler Scale (or WISC test, Wechsler Intelligence Scale for Children) in a modification for children and adolescents (from 6.5 to 16.5 years), adapted by A. Y. Panasyuk (Panasyuk, 2002) (Table 1).

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Table 1

Mean scores on the Wexler Scale for controls and children with mental retardation

Subtests / Groups of children	Control group	Group with mental retardation	P-level (*$p < 0.05$)
Verbal Scale			
Information	17.4	11.4	*
Comprehension	15.6	9.3	*
Arithmetic	16.2	11.7	*
Similarities	16.9	13.2	
Digit span	16.4	11.4	*
Vocabulary	16.6	11.2	*
Verbal assessment	101.1	68.2	*
Unverbal Scale			
Digit symbol	15.1	10.4	*
Picture completion	18.7	12.5	*
Block design	17.3	14.2	
Picture arrangement	18.8	13.6	*
Object assembly	16.7	12.3	*
Labyrinths	17.7	12.1	*
Nonverbal assessment	104.4	69.3	*
General intellectual indicator	102.8	68.4	*

Children with mental retardation were divided into 2 subgroups: A – with whom corrective work was carried out (n = 19, of which 10 were boys and 9 girls); In subgroup B, children with mental retardation (n = 17, of which 9 were boys and 8 were girls) did not perform this work.

At the first stage of the study, audiological examination of children by tonal audiometry and long-latency auditory evoked potentials was carried out, and the level of auditory perception was studied using neuropsychological methods. Audiological tests and registration of long-latency auditory evoked potentials were carried out in an audiological sound-insulated office.

Tonal audiometry method. Audiological evaluation was performed using tonal audiometry using a ORBITER922-2 audiometer (GN Otometrics & Madsen, Denmark) and a Martin Audio F8+ speaker (UK). The auditory threshold was measured using the ascending series method, when the pitch level is gradually increased in increments of 5 dB increase to appearance of test subject's reaction. The test started with a frequency of 1000 Hz, successively increasing the tone frequency: 2000, 4000 and 8000 Hz, and then tests were carried out in a region below 1000 Hz, successively lowering the tone frequency: 500, 250, 125 Hz. The retest was performed at 1000 Hz. The test tone was continuous and had a duration of 1–2 seconds.

Method of recording long-latency auditory evoked potentials. Registration of long-latency auditory evoked potentials, isolation and analysis of evoked potentials were carried out using the encephalograph "Encephalan 131-03" ("Medicom MTD", Taganrog). The active electrode was located in the brain region Cz (vertex) according to the international scheme "10-20" and connected to the first output of the amplifier (-). Reference electrodes were placed on the earlobes. The quality of the electrode installation was checked by monitoring the sub-electrode resistances by software. The biopotentials were amplified in the frequency band of 0.5–70 Hz and, after analog-to-digital conversion, analyzed using a basic encephalograph software package. 50 ms clicks were applied through the speaker. The stimulus was given no more than 1 times per 1 second with a random component, so that there was no addiction to the periodicity of the stimulus. The epoch of analysis was 500 ms with the number of averages – 100. Long-latency auditory evoked potentials were investigated in the temporal regions of the children examined. Pre-processing of brain bioelectric activity data was performed in MATLAB environment (The MathWorks). The signals were downsampled at 500 Hz and filtered using a window FIR Hamming filter in the range of 1 to 70 Hz. Each record was automatically scanned for artifacts that were removed from the analysis.

Neuropsychological testing. The study of auditory perception was carried out using adapted neuropsychological methods by T. G. Wiesel, A. V. Semenovich (Wiesel, 2005; Semenovich, 2019) in accordance with the psychophysical capabilities of children with mental retardation.

Assignment No. 1: Investigating a child's ability to perceive rhythms. Adaptation of the method T. G. Wiesel from the diagnostic block "Impressive speech. Gnostic prerequisites for the development of the phonetic-phonemic side of the speech 'Familiar melodies'" (Wiesel, 2005). The purpose of the study was to identify the ability to perceive rhythmic melodies. To do this, the children were presented with the recording of children's songs. In the first part of the examination, the child was monitored during logorhythmic classes. Explored the child's ability to move to different music (fast, slow, sad, fun music). In a musical lesson, the child was offered to perform dance moves to the music. The child's ability to move rhythmically to various melodies was evaluated. In the second part, the child was monitored during dance-rhythmic activities. They examined the child's ability to clap according to the tempo of the melody. Evaluation criteria: 1 point – the child shows dance abilities – in the movements of the child you can notice the ability to hear the rhythm of the melody; the child makes the claps on his own; 0.5 points – the child shows dance abilities, but performs the same type of actions (swirls, swings); makes slaps on imitation; 0 points – the child does not perceive sounding music.

Assignment No. 2: Investigating a child's ability to perceive and recognize speech. Adaptation of the method of T. G. Wiesel "Speech auditory gnosis at the onomatopoeia stage" (Wiesel, 2005). The purpose of this study was to identify the child's ability to perceive and recognize speech. Pictures of animals were used as material for visual reinforcement for the study. Execution progress: various onomatopoeic words built on differential signs of speech sounds were presented for hearing: hissing, whistling, buzzing, humming, growling, etc. An answer is possible in the form of a picture showing an object making this noise. Evaluation criteria: 1 point – the child perceives speech and responds with onomatopoeia; 0.5 points – the child attentively listens to speech, emotional activity and facial expressions are traced, as a response to speech; 0 points – the child does not perceive speech, leaves the researcher, an inadequate reaction to speech is possible.

Assignment No. 3: Research on the ability to perceive and reproduce rhythms. Adaptation of the Methodology Presented in A. V. Semenovich's Book "Introduction to Neuropsychology of Childhood" in the Section "Methods of Neuropsychological Examination. Auditory gnosis" (Semenovich, 2019). The goal is to reveal the ability to perceive and reproduce rhythm. Execution progress: the ability to perceive and reproduce rhythms was evaluated. The child was offered to complete the task "Pat like me" (light blows, up to 6 claps). The insufficiency of the auditory perception itself was differentiated from the difficulties of the child in the kinetic embodiment of the given program with either hand. Evaluation criteria: 1 point – the child is able to reproduce light rhythmic claps; 0.5 points – the child tries to reproduce rhythmic claps, but the task causes difficulties, or the child does not try to reproduce the claps, but listens carefully; 0 points – the child does not understand the task, does not pay attention to clapping, leaves the researcher, an inadequate reaction to speech is possible.

Data processing. High level (2.5–3 points) – the child copes with tasks. Shows the ability to perform rhythmic claps and rhythmic movements to various melodies, performs tasks on the perception and reproduction of speech. Average level (1–2 points) – completing tasks causes difficulties for the child, but he generally understands the task and tries to complete it. Low level (0–1 point) – completing the task causes significant difficulties. The child may not perform tasks at all. Inadequate actions are possible.

At the second stage, corrective work was carried out with children with mental retardation of subgroup A. Her goal was to create an optimal individual corrective and developmental environment using the Sensory Diet technique. *Content of corrective work*. Corrective exercises in Group A took place 3 times a week for 2 hours of extracurricular time for 6 months. Corrective work was aimed at the development of polysensory perception using neuropsychological technologies and the method of emotional-sensory impact: on the improvement of individual perceptual skills and training in their integrated use. This approach allows you to update the short-term reactions of children, encourage them to react emotionally, affecting sensory systems. That is, this approach involves the introduction of sensory stimuli into the activities of children, which allow you to awaken emotional reactions in children and create emotional-background support for the correctional process. Integrative interaction made it possible to form a joint activity with the child, during which it was necessary to create an emotional attitude for communication, to invite children not only to observe the subject, object, but also to actively participate in the study of its properties and objects associated with it (activity approach).

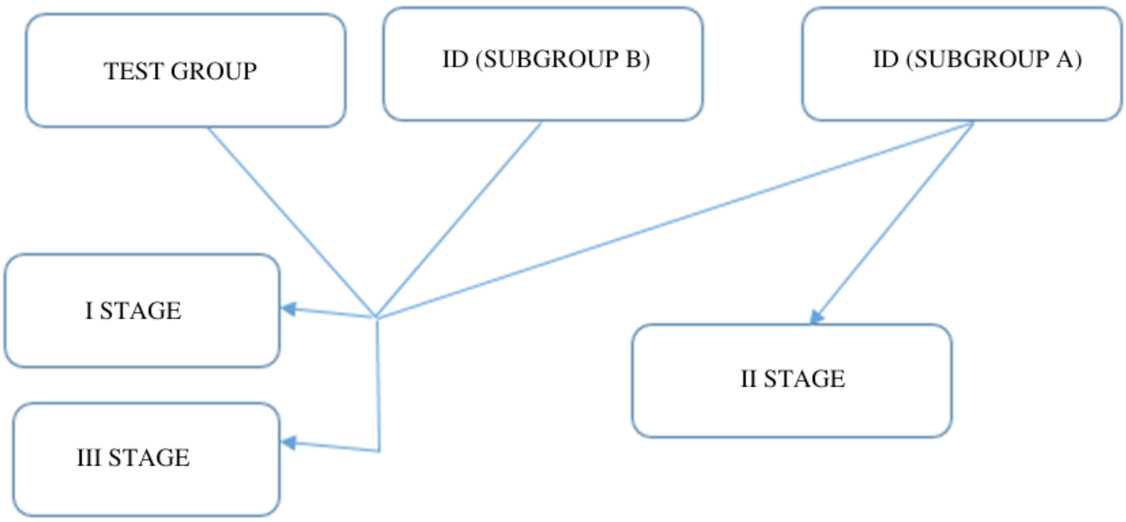
The system of conducting classes obeyed the principle of the optimal complex of stimuli on the child. The technique of sensory integration was built on the basis of an objective order of permanent relationships, which included three main chains of sensory connections: "tactile – proprioceptive – vestibular – visual"; "tactile – auditory – visual"; "tactile – taste – olfactory – visual". Both the entire direction of work and the thematic plan of individual classes on the development of polysensory perception methods were subordinate to these connections. Each task was aimed at the comprehensive use of certain sensory connections, but all sensory systems were always involved in them.

The specifics of the classes consisted in observing an individual approach to each child; classes were built on methods of sensory integration with minimal coercion when involving a child in them. To this end, classes began with such influences, to which the child responded well; after his active inclusion in the lesson gradually turned to less interesting for him. When avoiding any stimuli by the child, he was offered other stimuli.

At the third stage, repeated examination of children with mental retardation of subgroups A and B as well as children of the control group was carried out by tonal audiometry, registration of long-latency auditory evoked potentials and neuropsychological testing. A schematic representation of the study design is presented in Figure 1.

Figure 1

Study design



Notes: ID – children with intellectual disability; Stage I – the first examination of children using tonal audiometry methods, registration of long-latency auditory evoked potentials and neuropsychological testing; Stage II – corrective work; Stage III – re-examination of children using tonal audiometry methods, registration of long-latency auditory evoked potentials and neuropsychological testing.

Statistical processing of results. The data distribution was checked for normality using the Shapiro–Wilk test. Subject to the normality of the distribution of baseline data, Student's t-test was used to assess inter-group differences; if the normality hypothesis was not fulfilled, the Mann–Whitney test was used. The Fisher test was used to test the homogeneity hypothesis of the data sets compared. The Holm–Bonferoni correction was used to solve the problem of multiple comparisons. Differences at the $p < 0.05$ significance level were considered significant. Statistical comparisons of the data of the three groups (control, group of children with mental retardation of subgroups A and B) were carried out using a multivariate analysis of variance (MANOVA) implemented in the Statistica-10 application package. At $p < 0.05$, the differences were considered significant.

Results

At the first stage of the study, when studying the indicators of neuropsychological testing of children, the following results were obtained (Table 1). When studying the ability to perceive rhythm (Task No. 1), 26 children of the control group (76 %) rhythmically moved to the given music (depending on the tempo and mood of the melody), and also clapped their hands according to the tempo of the melody (1 point). The remaining 8 children of the control group were able to get 0.5 points each, since during the performance of this task they tried to capture the tempo and mood of the work, listened to the music, but they did not perform movements, and if they did, they were micro-movements lagging behind the musical rhythm of the melody; they also could not make claps to the beat.

When performing Task No. 2 (study of a child's ability to perceive and recognize speech speech) 32 students in the control group (94 %) correctly perceived speech sounds and reproduced them, 2 children in this group (6 %) had difficulty reproducing sounds, but they were emotionally active and correctly mimically reflected speech sounds. During the study of the ability to perceive and reproduce rhythms (Task No. 3), 29 students in the control group reproduced the required amount of claps without difficulty. 5 children of this group had difficulties: when presenting more than 4 claps at different rates, they sometimes made mistakes during reproduction (the tempo of the given rhythm changed or made the wrong number of claps). The sum of points in the control group for three tasks was 2.82, which corresponds to a high level of ability to perform rhythmic claps and rhythmic movements to various melodies, as well as speech perception and reproduction.

In subgroups of children with mental retardation, the following results were obtained after primary neuropsychological testing.

During the implementation of Task No. 1 to study the ability to perceive the rhythms of 16 children of subgroup A and 14 children of subgroup B were able to perceive music; when the melodies sounded, they had a revival reaction, including in the form of positive emotions, they raised their shoulders or moved with their whole bodies. These actions characterize the fact that children are able to hear a melodic composition, and it evokes positive emotions in them. The rhythm of the movements in this case in children did not correspond to the pace (fast/slow) and mood (funny/sad) of the melody. Their movements were chaotic and had a character different from a musical work. The remaining 3 students of subgroup A and 3 schoolchildren of subgroup B did not perceive melodies: they had poorly developed auditory reactions. These children did not differentiate the mood of the musical work (melodies of different emotional colors were perceived with a smile); some of these 6 children had an inadequate response to the task (they could walk around the room or lie on the floor during the task, which was assessed as a rejection of the proposed activity).

When analyzing the results of Task No. 2 (study of speech gnosis at the onomatopoeia stage), 1 student of subgroup A and 1 child of subgroup B scored 1 point each: during the task, these children showed adequate emotional responses and an attempt to portray an animal presented using stimulant material, and they correctly repeated speech sounds with pronounced articulation as adults. 15 students of subgroup A and 14 students of subgroup B scored 0.5 points during this task: children's answers were characterized by an emotional reaction to the presentation of illustrations with animals, children were interested in completing tasks, but they did not demonstrate voice reactions (in response to requests from an adult to repeat one or another combination of sounds, children picked up pictures and began to show in the direction of other pictures or objects where similar species of animals could be located or were depicted, i.e. children showed an understanding of the task being performed). The remaining 3 children of subgroup A and 2 children of subgroup B scored 0 points, since their responses were inadequate: there was no adequate emotional response to the presentation of pictures with animals and vocal reactions.

These children, when presenting pictures, could not concentrate on the task, were distracted, moved away from the diagnosis site; when again trying to offer to complete the task, they showed negative emotions and, sometimes, aggressive reactions.

When performing Task No. 3 (a study of the ability to perceive and reproduce rhythms), 12 children of subgroup A and 10 children of subgroup B scored 0.5 points: they began to perform the task for the presented rhythms, but were soon distracted; when playing rhythms, they were lost. The remaining 7 students of subgroup A and 7 children of subgroup B scored 0 points each: the children were inattentive to the teacher's appeals, did not listen to the given rhythm, did not repeat the clapping not only on their own, but also with a hint. The sum of points in the group of children with mental retardation for three tasks was: in subgroup A – 1.19 points, in subgroup B – 1.17, which corresponds to the boundary values between the low and average level of ability to perceive rhythms, perform rhythmic claps and rhythmic movements, perform onomatopoeia (Table 2).

Table 2

Results of primary neuropsychological testing

Groups / Test scores		Control group, number of children (%)	Subgroup A of children with mental retardation, number of children (%)	Subgroup B of children with mental retardation, number of children (%)
	1 point	26 (76 %)	0 (0 %)	0 (0 %)
Task № 1	0.5 points	8 (14 %)	16 (84 %)	14 (82 %)
	0 points	0 (0 %)	3 (16 %)	3 (18 %)
Average score		0.88	0.42	0.41
	1 point	32 (94 %)	1 (5 %)	1 (6 %)
Task № 2	0.5 points	2 (6 %)	15 (79 %)	14 (82 %)
	0 points	0 (0 %)	3 (16 %)	2 (12 %)
Average score		0.97	0.45	0.47
	1 point	29 (85 %)	0 (0 %)	0 (0 %)
Task № 3	0.5 points	5 (15 %)	12 (63 %)	10 (59 %)
	0 points	0 (0 %)	7 (37 %)	7 (41 %)
Average score		0.93	0.32	0.29
Total score for 3 tasks		2.82	1.19	1.17

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When examining the indicators of tonal threshold audiometry in the first stage of the study, it was found that in children with mental retardation, the thresholds of tonal audiometry were significantly higher relative to the control group of children by an average of 9–16 dB. The most significant differences (16.3 dB) in the tonal audiometry threshold were found between the control group and children with mental retardation at tone presentation with a frequency of 4000 Hz. In the speech frequency band in the control group of children, tonal audiometry thresholds were 16 dB lower on average compared to children with intellectual disability. There are no differences between subgroups A and B in tonal audiometry (Table 3).

Table 3

Results of tonal threshold audiometry (dB) in the free sound field in the control group and in students with mental retardation at the first examination

Frequency indicators	Control group	Subgroup A of children with mental retardation	Subgroup B of children with mental retardation
500 Hz	8.4 ± 2.8	21.7 ± 9.6*	22.3 ± 8.9*
1000 Hz	6.7 ± 3.9	23.4 ± 11.2*	22.7 ± 9.7*
2000 Hz	10.7 ± 4.2	19.6 ± 9.5*	20.4 ± 9.3*
4000 Hz	7.8 ± 4.6	22.3 ± 8.4*	21.6 ± 9.4*
Average value at speech frequencies, dB	8.9 ± 1.5	24.7 ± 11.2*	25.1 ± 10.5*

Note: * – significant differences of indicators relative to values in the control group (at *p □ 0.05*).

Parameters of long-latency auditory evoked potentials also differed between control children and students with mental retardation. It is known that the main peak of long-latency auditory evoked potentials in children is peak P1, the latent period of which decreases from 300 ms at birth to 60 ms in adulthood (Tavartkiladze, 2018). According to the results obtained in the control group of children, the latent period of this peak was 64.8 ± 3.1 ms, the average value in children with mental retardation of both subgroups, the latent period of peak P1 exceeded the values of the control group by 38 % (p □ 0.05). Mean values of latent periods of N1, P2, and N2 peaks were also higher in children with mental retardation (both subgroups) compared to the control group of learners, respectively, by 49 % (p □ 0.05), 45 % (p □ 0.05), and 30 % (p □ 0.05). There were no significant differences in the latent period of peak P3 between the control group and the group of students with mental retardation. The amplitudes of the N1–P2 and P2–N2 components in the control group exceeded the mean values in children with mental retardation (both subgroups) by 31 % (p □ 0.05) and 38 % (p □ 0.05), respectively. It was also established that out of 38 children with mental retardation, 32 children revealed a latent impairment of hearing function – a selective impairment of the perception of sound stimuli. This was manifested in more significant deviations relative to the average values: an increase in latent peak periods by more than 50 % and a decrease in the amplitudes of the analyzed components by more than 40 % in 15 % of children with mental retardation relative to the control group of students (Table 4).

Table 4

Parameters of long-latency auditory evoked potentials in test group children and students with mental retardation at the first examination

Parameters of long-latency auditory evoked potentials		Control group	Subgroup A of children with mental retardation	Subgroup B of children with mental retardation
Latency, ms	P1	64.8 ± 3.1	87.8 ± 4.7*	91.2 ± 5.1*
	N1	92.3 ± 6.4	136.3 ± 9.4*	139.5 ± 11.4*
	P2	145.8 ± 10.5	208.6 ± 11.3*	213.7 ± 16.8*
	N2	216.7 ± 12.3	282.7 ± 19.5*	279.4 ± 11.3*
	P3	287.6 ± 12.8	357.3 ± 28.9	352.8 ± 26.5
Amplitude, μV	N1–P2	12.4 ± 3.2	9.6 ± 1.7*	9.4 ± 0.9*
	P2–N2	8.9 ± 1.6	6.3 ± 1.2*	6.6 ± 1.1*

Note: * – significant differences of indicators relative to values in the test group (at *p* □ *0.05*).

During corrective sessions (second stage) with children with mental retardation of subgroup A, aimed at auditory and visual perception, exercises were adapted in accordance with the psychophysical capabilities of children. Classes to stimulate auditory perception aroused great satisfaction and interest in children, encouraged children to interact and communicate. Children gladly played didactic games on musical instruments, got acquainted with their properties and capabilities. During the course of classes, they were first offered items in accordance with their psychophysical characteristics. Subsequently, the child could study with other subjects. In addition to the development of auditory perception, other important skills were practiced during the classes: the ability to observe the sequence of actions, the development of attention, self-regulation of behavior and perseverance. Such skills are aimed at developing strong-willed qualities, play an important role in the development of the emotional sphere, are necessary for the harmonious development of the child.

Repeated testing at the *third stage* was carried out according to the same methods as at the first stage. The test results of the control group children did not change relative to the primary testing (at the first stage) (see Table 2). Analyzing the results of children with mental retardation, it was found that the studying subgroups A scored more points on neurophysiological tests compared to the first test (Table 5); in the students of subgroup B, the test results did not change (Table 2).

Table 5

Results of neuropsychological testing at re-examination

Groups / Test scores		Subgroup A of children with mental retardation, number of children (%)
	1 point	7 (37 %)
Task № 1	0,5 points	10 (53 %)
	0 points	2 (11 %)
Average score		0.55
	1 point	5 (26 %)
Task № 2	0,5 points	14 (74 %)
	0 points	0 (0 %)
Average score		0.63
	1 point	0 (0 %)
Task № 3	0,5 points	15 (79 %)
	0 points	4 (21 %)
Average score		0.39
Total score for 3 tasks		1.57

When performing Task No. 1 (ability to perceive and reproduce rhythms), 7 children (37 %) of subgroup A completed this task, gaining 1 point each. After corrective work, they were able to listen carefully to the rhythm and reproduce the rhythm to the music, as well as recognize the tempo and mood of the piece of music. 10 schoolchildren (53 %) of subgroup A performed Task No. 1 by 0.5 points: they performed the same type of actions (swirling or swinging from side to side), tried to repeat the rhythm and pace, clapping hands, but often made mistakes. 2 children of subgroup A (11 %) could not cope with the task: they could not recognize the musical work, although they already listened more carefully to the musical work, sometimes made claps to the beat of the music; despite the positive dynamics in the performance of this task, they scored 0 points each.

When performing Task No. 2 (assessment of the ability to perceive and recognize speech), 5 children of subgroup A (26 %) performed a task for 1 point: they began to cope with the task, speech perception and onomatopoeia became available to them (1 point). 14 children of subgroup A (74 %) completed the task, receiving 0.5 points each: the children listened more carefully to the experimenter's speech, looked at the pictures and showed emotions more differentially; observe a qualitative improvement in the performance of the task, although numerous errors in the reproduction of onomatopoeia were still observed.

When performing Task No. 3 (study of the ability to perceive and reproduce rhythms), positive dynamics was also observed: after corrective work, the number of children who completed the task increased by 0.5 points. 15 children in subgroup A (79 %) listened more carefully to the task, began to approach it more consistently, but they maintained erroneous reactions when they clapped their hands (they got confused, clapped in the wrong rhythm, repeated claps

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many times, etc.). The remaining 4 children of subgroup A (21 %) did not cope with the task, gaining 0 points each. Understanding the instruction for these children was still a difficulty, although a more attentive listening to the rhythm had already been observed, but without trying to replicate the rhythm. Chaotic movements, inadequate reactions, a change of mood were also observed. The sum of points for all three tasks of neuropsychological diagnosis of the study of auditory perception after corrective work was 1.57 points, which corresponded to the average level of ability to perceive rhythms, perform rhythmic claps and rhythmic movements, perform onomatopoeia (Table 5).

After corrective work (*stage three*), children with mental retardation (subgroup A) also showed a decrease in the thresholds of tonal audiometry (in contrast to children with mental retardation of subgroup B). Tonal threshold audiometry values in the control group were unchanged from the first examination. The reduction in the thresholds of tonal audiometry in subgroup A of children with mental retardation relative to the indicators in the first audiological test was 28 % ($0.1 > p > 0.05$) by 500 Hz, 24 % by 1000 Hz, 31 % ($0.1 > p > 0.05$) by 2000 Hz and 27 % ($0.1 > p > 0.05$) by 4000 Hz, as well as averaged values at speech frequencies – by 32 % ($0.1 > p > 0.05$) (Table 6).

Table 6

Results of tonal threshold audiometry (dB) in the free sound field in the control group and in students with mental retardation on re-examination

Frequency indicators	Control group	Subgroup A of children with mental retardation	Subgroup B of children with mental retardation
500 Hz	8.3 ± 2.2	15.7 ± 5.3*	21.7 ± 8.4#
1000 Hz	6.4 ± 3.1	17.8 ± 7.5*	22.8 ± 9.3#
2000 Hz	10.2 ± 4.3	13.6 ± 4.9*	20.2 ± 9.7#
4000 Hz	7.3 ± 4.1	16.3 ± 6.3*	22.4 ± 9.5#
Average value at speech frequencies, Db	8.5 ± 1.6	16.9 ± 7.2*	24.7 ± 9.9#

Note: * – significant differences in indicators in children with mental retardation in subgroup A relative to values in the control group; # – significant differences in indicators in children with mental retardation in subgroup B relative to values in children of subgroup A (if $p < 0.05$).

Repeated examination also evaluated the parameters of long-latency auditory evoked potentials in all groups of children (Table 7). In both the control group of students and in children with mental retardation of subgroup B, there were no significant changes in these indicators with respect to the primary examination using the method of recording long-latency auditory evoked potentials. In subgroup A of children with mental retardation after corrective work, a decrease in latent periods of P1 peaks was found (by 18 %; $0.1 > p > 0.05$), N1 (by 17 %; $p < 0.05$), P2 (by

19 %; 0.1 > p > 0.05), N2 (by 17 %; 0.1 > p > 0.05), P3 (by 15 %; 0.1 > p > 0.05) relative to the first examination. The amplitude values of the N1–P2 and P2–N2 peaks in the second study did not change from the first examination.

Table 7

Parameters of long-latency auditory evoked potentials in control group children and students with mental retardation at re-examination

Parameters of long-latency auditory evoked potentials		Control group	Subgroup A of children with mental retardation	Subgroup B of children with mental retardation
Latency, Ms	P1	62.3 ± 2.8	72.3 ± 2.8	93.7 ± 4.5#§
	N1	87.1 ± 5.2	112.7 ± 8.4*	128.6 ± 10.2§
	P2	141.6 ± 9.7	169.4 ± 7.8	202.3 ± 14.3§
	N2	211.2 ± 10.6	235.3 ± 13.4	263.6 ± 10.7§
	P3	282.3 ± 11.1	304.6 ± 21.2	344.5 ± 21.3§
Amplitude, μV	N1–P2	12.6 ± 3.5	11.7 ± 0.8	9.6 ± 0.8§
	P2–N2	8.7 ± 1.2	6.8 ± 0.6*	6.9 ± 0.9

Note: * – significant differences in indicators in children with mental retardation in subgroup A relative to values in the control group; # – significant differences in indicators in children with mental retardation in subgroup B relative to values in children of subgroup A; § – significant differences in indicators in children with mental retardation in subgroup B relative to values in children of the control group (if $p < 0.05$).

The results of correlation analysis of neuropsychological testing parameters, tonal audiometry parameters and long-latency auditory evoked potentials are presented below (Table 8).

As a result of the analysis, negative correlation associations were established between independent variables (indicators of tonal threshold audiometry and parameters of long-latency auditory evoked potentials) and dependent variables (indicators of neuropsychological testing). A high relationship was established between the score of all three neuropsychological testing tasks and the tonal threshold audiometry values at frequencies of 1000 Hz, 4000 Hz, and, especially, the averaged values at speech frequencies, as well as between the scores for Task No. 2 and the tonal threshold audiometry values at 500 Hz. In addition, a high correlation relationship was established between the values of latent periods of peak N1 and the scores of Task No. 3 obtained by examined children during neuropsychological testing; peak N2 and points for the fulfillment of Tasks No. 2 and No. 3; peak P3 and points for the fulfillment of Tasks No. 1 and No. 2.

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Table 8

Correlation associations between study scores in the control group of learners and children with mental retardation of subgroups A and B

Parameters		Indicators of neuropsychological testing		
		Task № 1	Task № 2	Task № 3
Indicators of tonal threshold audiometry				
500 Hz		r = –0,67	r = –0,81	r = –0,62
1000 Hz		r = –0,74	r = –0,84	r = –0,79
2000 Hz		r = –0,57	r = –0,61	r = –0,59
4000 Hz		r = –0,72	r = –0,81	r = –0,76
Average value at speech frequencies, Db		r = –0,76	r = –0,87	r = –0,81
Parameters of long-latency auditory evoked potentials				
Latency, Ms	P1	r = –0,53	r = –0,61	r = –0,64
	N1	r = –0,61	r = –0,65	r = –0,72
	P2	r = –0,62	r = –0,64	r = –0,69
	N2	r = –0,68	r = –0,71	r = –0,81
	P3	r = –0,72	r = –0,73	r = –0,54
Amplitude, μV	N1–P2	r = –0,42	r = –0,45	r = –0,32
	P2–N2	r = –0,34	r = –0,47	r = –0,27

The following results were obtained during analysis of variance (Table 9). The analyzed dependent factors were the level of intellectual development (ID) (levels: control group, children with mental retardation of subgroup A before and after corrective sessions), neuropsychological test results in points (levels: Task No. 1, Task No. 2, Task No. 3) and tonal threshold audiometry (TA) indicators (levels: frequency ranges 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, averaged value at speech frequencies, dB). The parameters of long-latency auditory evoked potentials (latency of peaks and amplitude of components) served as an independent factor.

Table 9

Results of analysis of variance (MANOVA) of neuropsychological testing parameters, tonal audiometry parameters and long-latency auditory evoked potentials

Parameters	Interaction of factors	F	P
Latency P1	ID × TA × Task № 1	1.568	0.34
Latency P1	ID × TA × Task № 2	1.146	0.21
Latency P1	ID × TA × Task № 3	1.221	0.13
Latency N1	ID × TA × Task № 1	1.324	0.36
Latency N1	ID × TA × Task № 2	0.854	0.32
Latency N1	**ID × TA × Task № 3**	**2.449**	**0.05**
Latency P2	ID × TA × Task № 1	1.983	0.07
Latency P2	ID × TA × Task № 2	1.221	0.13
Latency P2	ID × TA × Task № 3	1.317	0.35
Latency N2	**ID × TA × Task № 1**	**3.978**	**0.05**
Latency N2	**ID × TA × Task № 2**	**3.254**	**0.05**
Latency N2	**ID × TA × Task № 3**	**4.867**	**0.01**
Latency P3	**ID × TA × Task № 1**	**2.449**	**0.05**
Latency P3	**ID × TA × Task № 2**	**4.748**	**0.01**
Latency P3	**ID × TA × Task № 3**	**2.154**	**0.05**

Parameters	Interaction of factors	F	P
Amplitude of the component N1–P2	ID × TA × Task № 1	1.843	0.11
Amplitude of the component N1–P2	ID × TA × Task № 2	1.698	0.18
Amplitude N1–P2	ID × TA × Task № 3	1.439	0.43
Amplitude P2–N2	ID × TA × Task № 1	1.174	0.32
Amplitude P2–N2	ID × TA × Task № 2	0.929	0.48
Amplitude P2–N2	ID × TA × Task № 3	1.552	0.41

According to the results presented in Table 9, the productivity of Task No. 1 is associated to a greater extent with the values of tonal threshold audiometry and depends on the latency of the P3 peak of long-latency auditory evoked potentials. The efficiency of Task No. 2 performance is related to tonal threshold audiometry values and peak latencies of N2 and, especially, P3. The productivity of execution of Task No. 3 is determined by parameters of tonal threshold audiometry and latency of peaks N1, N2 and P3.

Thus, a connection has been established between the functional indicators of auditory perception and the effectiveness of performing neuropsychological tests by children with mental retardation. It is also shown that carrying out corrective classes with children with mental retardation, aimed at development of polysensory perception, affects improvement of parameters of threshold audiometry and individual indicators of long-latency auditory evoked potentials.

Discussion

The results of the study show that in children with mental retardation with a total intellectual index on the Wexler scale of 68.4, against the background of a low level of ability to perceive rhythms, perform rhythmic claps and rhythmic movements, perform onomatopoeia (according to the results of neuropsychological testing), the thresholds of tonal audiometry are increased. A statistically significant increase in latency of the P1, N1, P2, N2 peaks and a decrease in the relative amplitudes of the N1–P2 and P2–N2 peaks of long-latency auditory evoked potentials in children with mental retardation, which we obtained at the first stage of work in comparison with the control group, indicates the difficulties arising in the processing of an auditory stimulus in the primary and secondary auditory cortex, namely, in the perception and correct recognition of an auditory stimulus. After corrective work in subgroup A of children with mental retardation, a statistically significant increase in latency in comparison with the control group was noted only for the N1 peak, as well as a decrease in the relative amplitude of the P2–N2 peak. The results obtained after correctional work in subgroup A of children with mental retardation and their comparison with the data of subgroup B of children with mental retardation who did not participate in correctional activities indicate an improvement in the processing of the auditory signal in the primary auditory cortex.

Hearing processing disorder and the combined disorders of speech development and learning ability can be observed against the background of preserved peripheral hearing and is defined as «difficulties in processing auditory information in the central nervous system» (Miller & Wagstaff, 2011).

According to the results obtained at the first examination in children with mental retardation, the increase in the threshold of tonal audiometry was from 9 to 16 Db at different frequencies (with a maximum at speech frequencies). It is believed that a decrease in peripheral hearing (by 15–25 dB) is a conditional boundary between normal hearing and hearing loss, which negatively affects the development of speech processes that provide auditory and semantic function (Cunha et al., 2019). There is a perception that hearing processing disorder is not associated with deficits in sensory processing of information but is mainly the cause of attention deficit (Moore et al., 2010; Rosen et al., 2010; Ferguson et al., 2011). The question of whether auditory perception is generally related to cognitive processes is also actively discussed (Cacace & McFarland, 2013; Moore et al., 2013; Moore, 2018; Wilson, 2018). Some studies have argued that there is no direct relationship between auditory working memory and auditory perception (Mishra & Saxena, 2020). In our work, when re-examining children with intellectual disability after corrective work aimed at multy-sensor perception, a decrease in the thresholds of tonal audiometry, as well as latency of individual peaks of long-latency auditory evoked potentials, was established.

Based on the results of the analysis of the analysis of the neuropsychological testing parameters, the tonal audiometry parameters and long-latency auditory evoked potentials, it was established that the success of the neuropsychological tests and the passage of hearing survey is mainly associated with the values of the latency of the N2 and P3 peaks. These peaks are cortical potentials reflecting the arrival of auditory stimuli into the cortex of the greater hemispheres (Naatanen, 1998).

Thus, in children with intellectual disability, the entry of auditory information into the cortex of the greater hemispheres, its analysis and synthesis based on it occur with a delay. After the correction work, a decrease in the latency of these peaks was observed, which was accompanied by an improvement in the passage of neuropsychological tests related, among other things, to the recognition of both speech and non-speech sounds against the background of interference. This is partly consistent with the results of a study, which showed that knowledge of lexical characters and the ability to extract information from long-term memory are crucial for recognizing children's speech under interference signals: as a result of special classes with children, they have increased ability to recognize speech under interference (Nagaraj & Magimairaj, 2020).

We hypothesize that one mechanism of impaired auditory perception in children with mental retardation is the delay in the functional maturation of brain structures, primarily the left hemisphere. The perception and reproduction of speech involves many brain structures included in a network with a core consisting of three anatomical formations: the superior temporal gyrus (Heschl's gyrus, Wernicke's area), the medial temporal gyrus, the inferior frontal gyrus (Broca's area) (Friederici, 2011; Marslen-Wilson & Welsh, 1978; Mirman & Thye, 2018). At the same time, these structures are connected by bundles that form the ventral and dorsal pathways (Keitel & Gross, 2016).

It is known that in an adult, when perceiving speech and non-speech sounds in the left hemisphere, phase synchronization of gamma rhythms occurs normally, due to which high-frequency sounds are analyzed. When low-frequency sounds are perceived, phase synchronization of theta rhythms is recorded in structures of the right hemisphere (Giraud & Poeppel, 2012; Hickok & Poeppel, 2007; Abrams et al., 2008; Tang et al., 2016). Unlike adults in children in early childhood, high-frequency cortical rhythms prevail in the left hemisphere, and low-frequency rhythms are balanced in both hemispheres. The reason for such differences between adults and children is immaturity of the brain in early childhood, however, the presence of asymmetry of high-frequency patterns in the hemispheres of the brain in normally developing children of this age is a mechanism for facilitating the understanding of speech in masking conditions, i.e. in the presence of other sounds (maskers) (Thompson et al., 2016). The region of the left temporal gyrus plays a leading role in the detection and subsequent ignoring of irrelevant auditory information (Sakakura et al., 2022). With mental retardation in children, there is a delay in the maturation of the regions of the left hemisphere, and thus bioelectric processes compared to the norm (Buduk-ool, 2010), which probably prevents the timely formation of sound perception mechanisms, including in the speech range, especially in camouflage conditions. There is also an idea that one of the mechanisms of delayed speech development in children with mental retardation and minimal decrease in peripheral hearing is the relationship between impaired speech perception and high-frequency sounds (Cherkasova, 2003), which, in turn, negatively affects the speech and intellectual development of children. This is supported by the results of the study, according to which corrective measures for speech development lead to an improvement in the processing skills of auditory information in conditions of noise masking (Loo et al., 2016).

Thus, the study confirmed the hypothesis that the use of methods aimed at the development of multi-sense perception in children with mental retardation contributes to the improvement of auditory gnosis, which is proved by the results of both hearing and neurophysiological research and neuropsychological testing after appropriate corrective measures. The results of the study strongly support the need to identify minimal hearing impairment in children with intellectual disability, since the application of a comprehensive diagnostic system and individual approaches to the development of multi-sense perception to correct auditory impairment can contribute to reducing the formation of incorrect sound stereotypes and speech standards, as well as improving the ability to educate children with mental retardation.

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Conflict of Interest Information

The authors have no conflicts of interest to declare.