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Concern for the State of Development of Higher Auditory Functions in Children – a Proposal for Screening Diagnoses Based on the APD Medical Platform*

SUMMARY

The paper presents the results of the assessment of auditory functions in a group of fifty-nine children aged seven to ten. The tests were conducted on the diagnostic-therapeutic APD Medical platform, which enables carrying out the following tests: visual and auditory reaction test, adaptive one-syllable test for speech comprehension in noise, frequency pattern test (FPT), temporal resolution and auditory perception test (Gap Detection Threshold), adaptive frequency resolution test (DLF), and digital dichotic test (DDT). The participants were qualified for diagnosis on the basis of audiometric tests and surveys. The obtained results were compared with the values of normative higher auditory functions tests of the diagnostic-therapeutic APD Medical platform.

Key words: auditory processing disorders, higher auditory functions, sound discrimination disorders, psychoacoustic tests

INTRODUCTION

In recent decades, the problems of audiology have developed dynamically and their description covers the specificity of issues dependent both on the developmental variability of the hearing organ and dissimilarity between children and adults in the pathology of hearing impairments. Special importance is attributed to the assessment of differences in the activity of complex analytical-synthetic processes within the cortical part of the hearing analyzer; however, scholars have

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so far failed to unambiguously establish whether they pertain to neural processes occurring in the structures of the central auditory system, or whether they relate to auditory functions and skills (cf. Dajos-Krawczyńska et al. 2013, 9–14).

Indisputably, when anomalies occur at the cellular level, as a result of the delayed or disordered maturation of the central auditory system, or as a consequence of long-lasting and untreated or unaided peripheral hearing impairments, the capabilities of auditory information processing fundamentally change (Spionek 1965, 160–162 and 164–165; Sharma et al. 2002). A reduction in the functional efficiency of the cortical part of the hearing analyzer prevents correct recognition (identification) of isolated sounds or sound sequences, limits the development of skills in discriminating, ordering and integrating them into complex successions (complex structures determined by temporal sequence, cf. Spionek 1965, 241). It has been emphasized in recent years that these difficulties occur both within the ascending and descending pathways; what is of significant importance is that the integration and interpretation of auditory information also involves processes not connected with auditory modality while the accompanying neuronal desynchronization often results from an atypical functional asymmetry of the brain hemispheres and insufficient ability to transmit (not only auditory) information through interhemispheric connections (Wilson et al. 2004; Moore 2010, after: Dajos-Krawczyńska et al. 2013, 9–14; Majak 2013, 162).

Anomalies in the reception of an acoustic signal and dysfunctions associated with the inability to use it prevent full development of perception skills, whereby the acquisition of linguistic and communication competence is made difficult or even impossible (Grabias 1997, 9–36). Disorders in the area of auditory perception processes, sending and/or receiving sound signals, make contact with the surrounding world difficult and communication through language impossible. That is why scholars devote so much attention to the audiogenic determinants of speech disorders and to the problems of complex auditory perceptions (cf. *inter alia* Grabias 1994; 1997; 2001; 2007; Spionek 1965; 1970; Krakowiak 2012; Kurkowski 2002; 2013). Especially worth noting are difficulties in implementing the so-called higher auditory functions (with the normal reception of stimuli in the peripheral structures), among which such processes are named as: the ability to locate the source of sound, the ability to discriminate sounds of different frequency, the ability to recognize sound patterns differing by frequency or volume, the ability to discriminate and classify sounds of different duration and their temporal integration, the ability to identify competing acoustic signals or to receive distorted signals (including speech) (ASHA 2006).

Dysfunctions connected with higher auditory processes have a negative impact on the child's communicative abilities and educational success. The survey conducted among primary and junior high school students and teachers for the present studies[1] shows that the number of children with linguistic communication disorders of different etiology continually increases. Prevention in this area should cover individuals of all ages, the diagnosis of difficulties and their rehabilitation playing a special role in the case of children and young people. The results of studies carried out in the world in the last fifty years show that the problem affects ca. 2–3% of children (Chermak, Musiek 1997; Chermak et al. 1998; Wilson 2003; Katz 2007); particularly worth noting is the fact of the occurrence of auditory processing disorders among dyslectics (Heiervang et al. 2002; Wilson 2003; Rosen 2003; Dowes, Bishop 2010; Ferguson et al. 2011; Lewandowska et al. 2013), among individuals with specific language development disorders (Rosen 2003; Hill et al. 2005; Ferguson et al. 2011; Vandewalle et al. 2012; Rocha-Muniz et al. 2014), among children with special learning difficulties (Sharma et al. 2009) and among people with the attention deficit hyperactivity disorder (ADHD).

The need to develop the efficiency of the hearing analyzer requires first of all exercises focused on "absorbing" auditory sensations and perceptions, on their analysis and synthesis. Intensified activity in this area supports the maturation of subcortical centers, which, in turn, stimulate the development of the cortical part of the hearing analyzer in the temporal lobe. Experiencing of sounds determines the ability to identify and integrate them into complex structures, thereby speeding up the lateralization of the dominant hemisphere. Regarding the prophylactic measures in preventing school difficulties and the increase in the number of children with linguistic communication disorders of different etiology, stress is laid on the necessity of taking care of the proper acoustic environment and on the role of direct therapeutic intervention geared towards improving higher auditory functions interrelated with attention and memory processes as part of various auditory trainings (Skoczylas et al. 2012a; 2012b; Senderski 2014; Senderski et al. 2016).

Regrettably even today, despite the admonitions by H. Spionek, which go back to the nineteen-seventies (Spionek 1973, 236), the diagnosis of a child still does not include a complete and thorough assessment of the realization level of auditory functions as a significant aspect that changes with age and acquired experience, and which embraces the assessment of the analysis and synthesis of successive patterns of sound stimuli, taking achievements of psychoacoustics into account.

[1] Studies confirm that over the last several decades the number of children with auditory processing disorders has increased. Learning difficulties and worse functioning in the school environment have been identified in 10% of students. They have been diagnosed with disorders within almost all higher auditory functions, the most frequent being disorders in the processes of frequency discrimination and speech comprehension in noise (Skoczylas et al. 2012). Studies were also conducted under the research project implemented in the Logopedics Center as part of the 9th University of Silesia Speech Therapy Days in 2017.

One of the possibilities of preventive measures is the APD Medical platform, developed in Poland in recent years, which enables specialists, *inter alia*, logopedists, psychologists, teachers, and therapists, to assess the level of the advanced development of auditory functions in children aged four years or more, and to compare the obtained results with reference values defining the degree of their development in order to determine further therapeutic management (Senderski et al. 2016)[2].

MATERIAL AND METHOD

The article presents the results of assessment of auditory functions in a group of fifty-nine children living in the vicinity of Katowice. The tests were conducted in appropriate acoustic conditions (the silence room in the University of Silesia Logopedics Center) under the research project assessing the level of higher auditory functions among primary school pupils in the province of Silesia, implemented at the Faculty of Philology Logopedics Center, University of Silesia in Katowice. At first, the participants were qualified for diagnosis on the basis of results of audiometric measurements[3]. Children whose hearing threshold in tonal audiometry did not exceed 20 dBHL were qualified for the APD Medical platform tests. The child's medical history and the course of his/her psychomotor and language development were assessed based on the questionnaire available at www.neuroflow.pl.

The APD Medical platform works after connecting the computer to the Internet[4] and enables conducting psychoacoustic APD tests: auditory reaction test and visual reaction test, adaptive speech in noise test (ASPN) for syllable comprehension, and ASPN for sentence comprehension, the test of sequence of tones of varied pitch (Frequency Pattern Test), gap detection threshold test (GDT), difference limen for frequency test (DLF) and dichotic digit test (DDT)[5].

The goal of tests was to make a preliminary approximate diagnosis and assessment of the level of maturity of auditory functions in children aged from seven to ten years (Table 1).

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[2] Significantly enough, the tests available on the APD Medical platform are recommended both in the report by J. Jerger and F. Musiek (2000), and recommended by ASHA (2006).

[3] The hearing sensitivity was assessed using the Maico MA-1 screening audiometer with audiometric DD-45 earphones, additionally equipped with Amplivox Audiocups (headset enclosures with external noise-excluding properties). Auditory tests of the APD Medical platform were conducted using DD-45 earphones with Amplivox Audiocups external noise-excluding enclosures, connected to the audio output of a PC portable computer.

[4] Cf. www.neuroflow.pl

[5] The description of tests together with testing procedure is discussed in the article by A. Senderski et al. (2016, 99–106).

Table 1. The percentage of subjects in individual age groups

Group : 7-year-olds	25.00%
Group: 8-year-olds	24.00%
Group: 9-year-olds	24.00%
Group: 10-year-olds	27.00%

Source: own work

The following tests were conducted in younger children (aged seven years): the auditory and visual reaction tests[6], adaptive speech comprehension in noise test (ASPN for syllables and ASPN for sentences)[7], screening dichotic digit test (DDT)[8], screening frequency pattern test – (discrimination of frequency sequences FPT)[9]. In the 8- to 10-year age groups the battery of tests was broadened with the adaptive gap detection threshold test (GDT) and adaptive difference limen for frequency test (DLF)[10].

The obtained results confirmed the difficulties found in some of the children, concerning the efficiency of the hearing analyzer and the need for intense therapeutic work to stimulate higher auditory functions. Some of the children were qualified for the "Neuroflow" active auditory training. The obtained results were compared with normative values for tests for higher auditory functions on the diagnostic-therapeutic APD Medical platform (Cf. Senderski et al. 2016, 103–106).

[6] The visual and auditory reaction test served to assess the duration of single responses to a specific auditory and visual stimulus, and to test the course of the reaction to a stimulus. It also enables observation of the level of neuromuscular coordination during the execution of tasks, and enables testing the level of the child's reactivity to a stimulus (cf. Senderski et al. 2016, 99–106).

[7] Tests for speech in noise comprehension enable the assessment of correctly recognized one-syllable words and sentences occurring in the context of the so-called multitalker babble. The result of the test is the signal to noise ratio, (SNR) for 50% of correctly recognized words (Senderski et al. 2016, 102 and 104–105; Funte, McPherson 2007, 71–73).

[8] The goal of the dichotic digit test is to repeat all the heard digits (testing of distracted attention exclusively) and to assess the degree of maturity of the central auditory system as well as to determine the specialization level of the cerebral hemispheres for language stimuli and to verify the ways of information transmission between the cerebral hemispheres (Senderski et al. 2016, 101–102; Funte, McPherson 2007, 72).

[9] The screening frequency pattern test enables detection of organic damage to the central nervous system is a test used for diagnosing auditory processing disorders (Senderski et al. 2016, 102 and 104–105; Funte, McPherson 2007, 71–73).

[10] The adaptive gap detection threshold test (GDT) and adaptive difference limen for frequencies test (DLF) serve to assess the ability to detect changes while an auditory stimulus lasts, and to test the ability to detect time intervals between auditory stimuli (Senderski et al. 2016, 102 and 105; Funte, McPherson 2007, 70–71).

RESULTS

The largest group of subjects were children aged ten, the second-largest group were seven-year-olds. The groups of eight-year-old and nine-year-old children were equal in number (Chart 1).

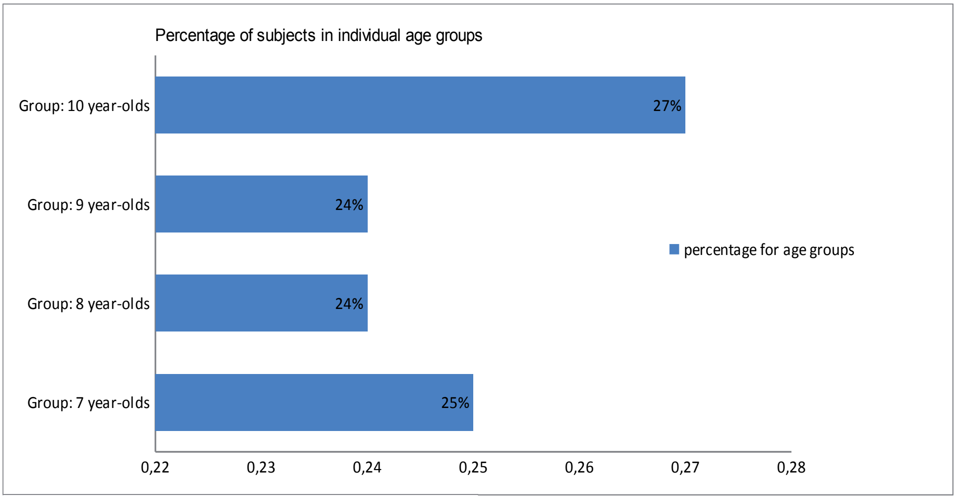

Chart 1. Percentage of subjects in individual age groups
Source: own work

The parents of both the youngest and the oldest children expressed the need to assess the level of auditory processing: in the youngest group – because of the educational start, to test the child's auditory adaptation abilities in the new environment and assess the level of the ability to synchronize the stimuli of visual-auditory-motor modality as part of the execution of complex tasks, *inter alia* the acquisition of reading and writing skills. The parents of the oldest children expected diagnosis to be combined with verification of the level of school achievements compared with the advanced level of higher cognitive processes determined by the state of higher auditory functions.

The tests for responses to visual stimuli were carried out almost in 100% in all age groups (Table 2). The obtained percentage of correct answers is connected with the children's high proficiency in learning computer games and using the electronic media. The average time of visual reactions was 404 ms for the youngest group and was lower than the normative value defined at 550 ms. A similar situation developed in older age groups, in which the children obtained results at 350 ms for eight-year-olds and ca. 300 ms for nine- and ten-year-olds. The results for auditory reaction time were somewhat different. In all the age groups, the children scored higher reaction times as compared with the normative reference values for individual age groups (Auditory Reaction Test value for seven- and eight-year-olds is 550 ms, for nine-year-olds it is 500 ms, and the reference value for ten-year-olds is 450ms). Response to a visual stimulus is usually longer than to an auditory one. In the youngest group as many as six subjects obtained a lower result, which accounts for 40% of the subjects. Mean results for the visual reaction test and auditory reaction test in individual age groups are shown in Table 2.

Table 2. Visual reaction test results and auditory reaction test results in groups of 7- to 10-year-olds

	7-year-olds		8-year-olds		9-year-olds		10-year-olds	
	P	NP	P	NP	P	NP	P	NP
Visual Reaction Test (VRT)	12	3	13	1	13	1	16	–
	79.96%	20.01%	92.82%	7.14%	92.82%	7.14%	100%	–
Auditory Reaction Test (ART)	9	6	14	–	12	2	15	1
	59.98%	40.02%	100%	–	85.72%	14.28%	93.75%	6.25%

* P – normative score; ** NP – below norm score
Source: own work.

The ability to recognize competing acoustic signals and the reception of distorted signals was associated with the assessment of auditory-spatial attention because hearing deficits occurring in this area are manifested in problems with speech sound perception (phoneme discrimination) when the sounds appear accompanied by noise (e.g. Cunningham et al. 2001). The results of the ASPN test, both for words and sentences, were lower in the group of younger children (cf. Table 3).

Table 3. Results for speech in noise comprehension test in groups of 7- to 10-year-olds

	7-year-olds		8-year-olds		9-year-olds		10-year-olds	
	P	NP	P	NP	P	NP	P	NP
ASPN-s	10	5	10	4	12	2	13	3
	66.65%	33.35%	71.44%	28.56%	85.72%	14.28%	81.25%	18.75%
ASPN-z	8	7	13	1	13	1	14	2
	53.31%	46.69%	92.82%	7.14%	92.82%	7.14%	87.5%	12.5%

* P – normative score; ** NP – below norm score
ASPN-s – Adaptive Speech in Noise test (ASPN – one-syllable word test)
ASPN-z – Adaptive Speech in Noise test (ASPN – sentence test)
Source: own work.

The results obtained from dichotic digit tests showed that on average 30% of subjects in all age groups had difficulties in processing two different acoustic signals reaching the left and the right ear at the same time (cf. Table 4).

Table 4. Results of the dichotic digit test in groups of 7–10-year-olds

	7-year-olds		8-year-olds		9-year-olds		10-year-olds	
	P*	NP**	P*	NP**	P*	NP**	P*	NP**
DDT RE	10	5	11	3	9	5	13	3
	66.65%	33.35%	78.58%	21.42%	64.26%	35.74%	81.25%	18.75%
DDT LE	10	5	11	3	10	4	15	1
	66.65%	33.35%	78.58%	21.42%	71.44%	28.56%	93.75%	6.25%

* P – normative score; ** NP – below norm score
DDT RE – screening dichotic digit test for the right ear
DDT LE – screening dichotic digit test for the left ear
Source: own work.

In children aged 7 to 10 years, the difference between the results for the right ear and the left ear was not statistically significant. This evidences the not yet developed ability to discriminate and classify sounds of different duration and their temporal integration, and the need to include exercises that stimulate the ability to recognize competing acoustic signals. This was confirmed by results obtained in tests enabling the investigation of the ability to discern differences between sounds, to discriminate sound sequences and discriminate sound duration (cf. Table 5).

The results obtained in frequency discrimination tests confirm great difficulties in correctly decoding sounds combined with a verbal response. The results obtained in the seven-year-olds group indicate a far lower percentage of correctly repeated sequences in the FPT as compared with children aged eight to ten years.

DISCUSSION

In view of the significance of auditory perception processes and the role of auditory functions in the acquisition of linguistic and communicative competence, the question of diagnosing and developing them remains extremely important. The results obtained based on the carried-out screening tests for high auditory functions show how many processes in auditory processing need to be improved. The state of research is shown in Chart 2.

Table 5. Test results: Frequency pattern test, gap detection threshold test (adaptive temporal resolution and auditory perception) and difference limen for frequency test (adaptive frequency resolution) in groups of seven- to ten-year-olds

	7-year-olds		8-year-olds		9-year-olds		10-year-olds	
	P*	NP**	P*	NP**	P*	NP**	P*	NP**
FPT	9	6	10	4	9	5	14	2
	59.98%	40.02%	71.44%	28.56%	64.26%	35.74%	87.5%	12.5%
GDT	–	–	14	–	11	3	14	2
	–	–	100%	–	78.58%	21.42%	87.5%	12.5%
DLF	–	–	7	7	9	5	10	6
	–	–	50%	50%	64.26%	35.74%	62.5%	37.5%

* P – normative score; ** NP – below norm score
FPT – the test of sequence of tones of varied pitch
GDT – adaptive gap detection threshold test
DLF – adaptive difference limen for frequency test
Source: own work

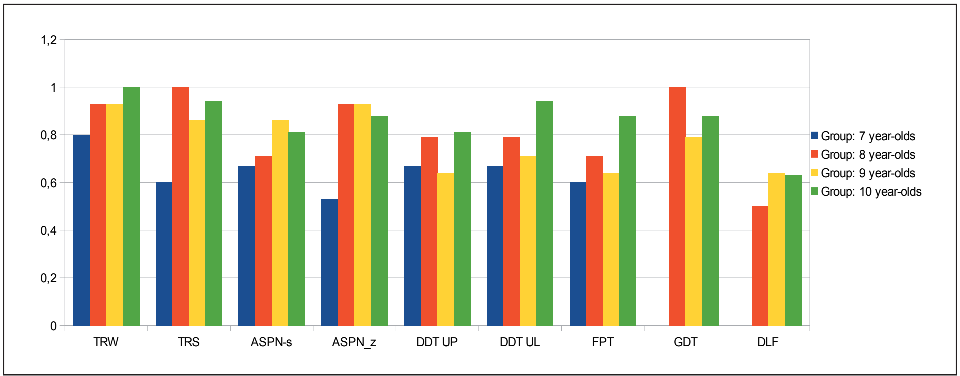

Chart 2. Comparison of correct results of assessment of higher auditory function tests of the APD Medical platform

Source: own work.

Both the tests for speech comprehension in noise and the results of DDT, FPT, adaptive GDT and adaptive DLF tests reflect the maturity level of the auditory system and define the areas that require intensive therapeutic management. The normal functioning of the child and his/her development depend on the development of the processes of sensory systems integration. Difficulties in processing sensory, *inter alia*, auditory and visual, sensations can be the cause of educational problems, particularly difficulties in the acquisition of reading and writing abilities.

The results obtained in the studied groups confirm that many pupils exhibit both phonological deficits and disorders in the integration of auditory stimuli, and difficulties in attention processes (cf. Skoczylas et al. 2012a, 13; Przybyla 2014/2015, 400). The state of research is shown in Chart 3.

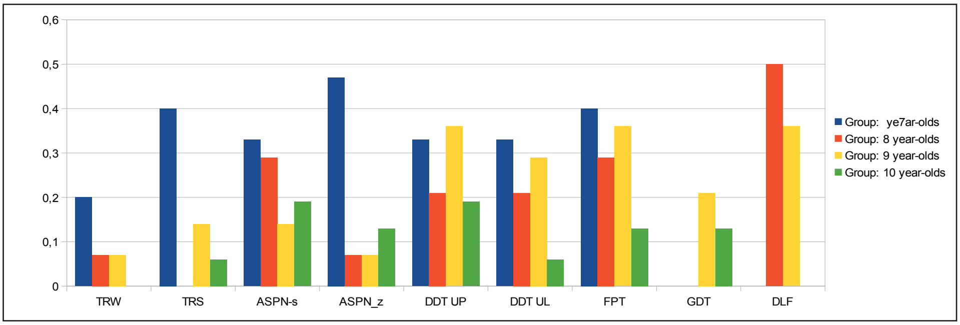

Chart 3. Comparison of incorrect results of assessment of higher auditory functions of APD Medical platform tests

Source: own work

Thus, for example, in the seven-year-olds group, as many as ten children were characterized by the decreased level of higher auditory functions, which were directly associated with the inability to obtain positive results in the conducted tests. Three of the seven-year-olds obtained incorrect scores in all APD Medical platform tests, which may be directly connected with the manifestation of attention deficit and considerable difficulties in understanding speech in noise. In the group of eight-year-olds, auditory attention disorders were found in one boy. In all the age groups, the greatest difficulty was connected with disorders in identifying, discriminating, and remembering the acoustic features of speech sounds, and complex sequences of their arrangements (difficulties characteristic of the clinical profile related to phonological deficit) and it was manifested in the low results in ASPN, DDT, often FPT, GDT, and DLF tests. In the group of seven-year-olds, there were three such children while among the eight-year-olds the problem concerned one girl. As many as four children (three boys and a girl) in the group of nine-year-olds grappled with such difficulties, while among the ten-year-olds as many as three children (two boys and a girl) had problems. Among the subjects there were also children whose auditory perception disorders were observable first of all in the DDT and FPT tests, and were connected with a deficit in processing rapidly-succeeding sounds and with reduced skills in discriminating acoustically similar sounds. Four seven-year-olds found it difficult to simultaneously integrate information to use it effectively. Two more eight-year-olds and one nine-year-old had to cope with the problem of delayed myelinating processes and with achieving the maturity of interhemispheric transmission.

The conducted assessments confirm, although to a limited extent, that because of the significance of auditory processes and the role of the maturation of the auditory system it is necessary to make screening diagnoses of higher auditory functions for different age groups among children and schoolchildren. On the basis of the studies, it is possible to early include in the process of therapeutic management the individuals in whom there are symptoms of abnormalities in auditory perception in order to appropriately influence their educational progress and develop their admiration for the abundant and diverse world of sounds.

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