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Audiological Clinical Validation of New Original Romanian Speech Audiometry Materials for Evaluation of Communication Abilities in Children of Primary School Age

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Abstract

Communication and speech pathology in children is determined mostly by hearing loss and less frequently by neurological or psychological disorders. The pure tone hearing and the capacity of sound discrimination and voice perception are determinant in speech intelligibility and development of speech production, important factors conditioning cognitive and school performances and social integration. A particular condition is ANSD (auditory neuropathy spectrum disorders) with a rising prevalence in last years. Despite the good tonal hearing, these children cannot reach normal speech and cognitive development. The assessment of hearing and speech understanding in children has to include tone and speech

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audiometry according to age and psychoneural condition. Different speech intelligibility tests have been developed for some languages, but calibrated materials for Romanian were not clinically validated until now. We created a kit test using monosyllabic and bisyllabic words from spoken language corresponding to the normal speech development between 7-12 years old. The words were filtered by special software to select the most common and frequency spectrum homogeneous word lists. The aim of study was to clinically assess and validate this material in Romanian language for speech audiometry. The audiological assessment was made in standard test conditions and the results were statistically analyzed. This original new Romanian speech test for evaluation of hearing and communication abilities in primary school aged children was statistically proved as a valid clinical tool for widely use in the evaluation of hearing loss or communication disorders and also for monitoring hearing and speech development progress in children during medical and speech therapy rehabilitation.

Keywords: communication abilities; speech audiometry; speech disorders; auditory neuropathy; Romanian language.

Introduction

Hereditary factors, psychosocial environment and education are essential factors and conditions that contribute to psycho-physical and cultural development of any normal person or persons with sensory, motor or mental deficits. If the physical development requires child care, food and personal care, psychosocial development requires the existence of communication and human relationships means (Ferguson *et al.*, 2013). Humans as social beings and the generation of social realities are centered on relations between people. The language, communication and discourse are considered means of interaction between individuals who construct multiple realities. The social environments are created by people who communicate through language, each of them influencing and limiting the responses of the other (Cojocaru, Bragaru & Ciuchi, 2012). Any intervention or disorder in human speech and language development has, first of all, a sociological character. In this context, the hearing is critical to speech and language development, communication and learning (ASLHA, 2015a) and the early detection, intervention and rehabilitation are absolutely necessary, starting from birth to teenage (Yoshinaga-Itano, 2013).

Children with hearing loss or auditory processing problems continue to be an under identified and underserved social category. It has affirmed the fact that the earlier hearing loss occurs in a child's life, the more serious the effects on the child's development and the earlier the disorder is identified and rehabilitation begun, the less serious the ultimate impact (ASLHA, 2015b). The delay in the

development of receptive and expressive communication skills (speech and language) causes learning problems that result in reduced academic performance and the communication difficulties often lead to social isolation and poor self-esteem influencing vocational choices (Tomblin *et al.*, 2015).

Universal newborn hearing screening program applied also in our region since 2008 offers the solution of early detection and diagnosis of auditory disorders with early intervention, meaning hearing restoration as soon as possible after diagnosis, with the most appropriate method according to diagnosed pathology. On the other hand, an auditory impairment acquired in pre-school and primary school aged children may go unnoticed being detected late when specific effects appear: vocabulary develops more slowly, the sentence structure is less complex, the speaking and diction are affected, the writing-reading processes can be delayed, the academic achievement are poorer (Kenna, 2015; Burlea, Burlea & Milici, 2010).

Auditory Neuropathy Spectrum Disorder (ANSD) also known as Auditory Dyssynchrony (AD) or Auditory Neuropathy (AN) is a special category of auditory disease. The dysfunction of auditory system could be explain by three topographic lesions: the damage of internal hair cells of organ of Corti, the synaptopathy (dysfunction in neurotransmission in synaptic space from internal hair cells of cochlea to the first neuron of auditory pathway from Corti ganglia) and the third is the auditory nerve dysfunction - electrical signals received from the cochlea and transmitted to the brain are dyssynchronous. In any of these conditions the auditory signals are not synchronized so information is not relayed to the brain in a clear and consistent manner. The clinical manifestations of auditory neuropathy/dyssynchrony vary from near normal hearing to profound hearing loss in pure tone audiometry but with bad or no speech recognition (Kaga, 2016; Norrix & Velenovsky, 2014; Starr *et al.*, 1996; Kaga *et al.*, 1996).

Auditory Processing Disorder (APD) also referred to as Central Auditory Processing Disorders (CAPD) is characterized by difficulty hearing and understanding speech even though no measureable hearing loss exists. Children with APD may exhibit a variety of listening and related complaints such as difficulties in understanding speech in noisy environments, following directions, and discriminating similar-sounding speech sounds. APD is often confused with other disorders such as ADHD (Attention-deficit/hyperactivity disorder), learning disabilities, language impairment, cognitive deficits or socio-emotional delays. A multidisciplinary team approach is highly recommended for precise diagnosis of this disorder including speech-language therapist, psychologist, classroom teacher, parent, physician and audiologist (Heine & O'Halloran, 2015; Bellis & Bellis, 2015).

Given the complexity of the evaluation of children with hearing loss or auditory processing problems, there is imperative necessary to use a comprehensive battery of appropriate and adapted audiological tests that are chosen based on the person's age, auditory problems, language and cognitive abilities. Such an audiological test battery has not been created so far for Romanian language. The assessment of speech perception in French has been studied with the phonetic test of J.C. Lafon - lists for children since 1956 (Lafon, 1956; Helias, Chaurand & Lafon, 1990; CNA, 2006) and monosyllabic and bisyllabic words list of Fournier (Fournier, 1951). In England there has been used the Fry tests for speech audiometry since 1961 (Fry, 1961) and The Manchester Junior word list (MJ) is commonly used with children and the Arthur Boothroyd (AB) list with adults and older children (Westhorp, 2009). Also, for English language, in the USA the most common tests used in speech evaluation is Harvard Phonetically Balanced (PB-50) Word Lists, Central Institute for the Deaf (W-22) Monosyllabic Word Lists and the Maryland CNC Test developed by Causey *et al.* (Causey *et al.*, 1984; ASLHA, 2015). In German speech audiometry are used the tests developed by Karl Heinz HahIbrock (Feldmann, 2004) known as the Freiburg speech intelligibility test.

The Romanian language particularities make impossible the translation and adaptation of other languages speech tests because of phonetic and morphological characteristic features. Also, the frequency word in spoken language adapted to normal language development for every age is specific to each country and for every language a speech evaluation test battery should contain the most commonly used words and phonetically balanced material (Johns *et al.*, 2012; Krull *et al.*, 2010). We present the clinical validation of a new and original audiological speech understanding test useful in evaluation of communication abilities in primary school children.

Methods

Aims and objectives

Aims and objectives of the study were the clinical validation for a new and original speech audiometry test battery for Romanian language designed by us to be used in the evaluation of speech perception and communication abilities of children from primary school age group. Our purpose was to demonstrate that any generated list with our algorithm can be clinically used with a high degree of confidence. Thus, the same results should be obtained across multiple measurements with randomized different lists presentations in similar standard testing conditions without statistically significant differences between all presented word lists. Another main objective of our study was to demonstrate for the normal hearing children that the words recognition in quiet across our lists is statistically related to the linguistic normality for this interval of age.

Study group

The study group included a number of 24 children (equivalent to 48 ears or test units) aged between 7 and 12 years. The including criteria except the age, were: normal aspect of the ear, bilateral normal hearing and age-appropriate cognitive and linguistic development, good pronunciation, Romanian native speakers. They have been auditory assessed in Audiology Department of Rehabilitation Clinical Hospital Iasi, Romania, with the informed consent of their parents.

Material and methods

For all the subjects of the group have been conducted otomicroscopy, tympanometry and pure tone audiometry. We included in the study the children with normal aspect of the ear, tympanometry of type A (normal) and a pure tone threshold ranging from 0 to 20 dB for every tested frequencies in pure tone audiometry (250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 8000 Hz). All audiometric assessment took place in a double-walled, sound-treated room in Audiology Department. The Interacoustics audiometer AD629 was calibrated according to actual audiometry standards. The pure tone audiometry (PTA) and also the speech audiometry were made using closed circumaural headphones (Sennheiser HDA 200). The Hughson-Westlake method was used for PTA procedure and the results were stored for further analyses in the database.

Speech perception was tested monaurally in quiet using a recorded speech audiometry material. Speech audiometry test battery represents an original audiological evaluation tool developed in our department, consisting of 50 phonetically balanced bisyllabic words lists and 20 phonetically balanced monosyllabic words lists adapted to the level of language development for this category of age. The linguistic material for speech audiometry has been gathered based on the principles of early preschool education curriculum and primary school program developed and approved by Ministry of Education and Scientific Research from Romania, governing the education standards in our country. We created a language corpus for primary school aged children using the most frequently words according to school textbooks available for this stage. The material was audio recorded in a television studio using a professional female voice.

The phonetically balanced words lists were generated using our own and original algorithm. A balanced list should expose the tested subject to all frequencies spectrum of common spoken language approximately in the same manner that it is naturally exposed to a long speech. The algorithm extracted by spectral-statistics analysis of a Romanian spoken language corpus, the ideal criteria used in list generation. In this way, the frequency spectral characteristic for every list is very similar to ideal distribution of whole speech and the generation of lists was based on genetic algorithms. We generated 50 bisyllabic words lists and 20

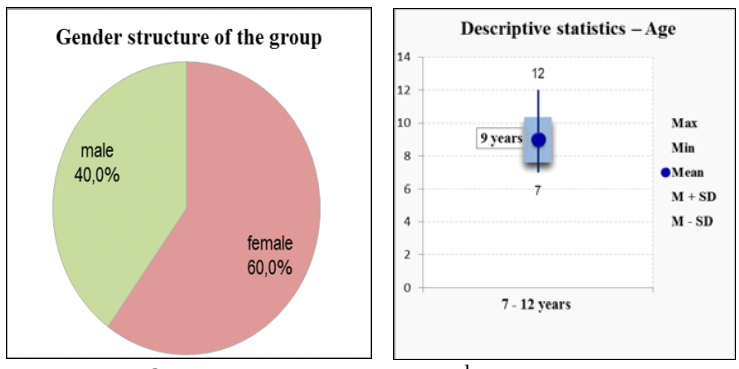
monosyllabic words lists, every list containing a number of 10 words, corresponding to the most actual languages speech audiometry tests.

For every subject included in our study the pure tone average was determined in every ear using 3 frequencies (3 FAHL – Three Frequency Average Hearing Level: 500 Hz, 1000Hz and 2000 Hz) and also 4 frequencies (4 FAHL – Four Frequency Average Hearing Level: 500 Hz, 1000Hz, 2000 Hz and 4000 Hz). The lists were presented at different intensities to all children so each list to run at all intensities. For every list at a certain intensity was determined the Word Recognition Score (WRS - the percent of correctly recognized words) and for every tested ear were calculated the SRT (Speech Recognition Threshold meaning the minimum hearing level for speech at which an individual can recognize 50% of the speech material) and the Maximum Recognition Threshold (MRT - minimum hearing level for speech at which the highest percentage of words are recognized). The coding used for the generated lists was 7_12 – for the age range followed by word syllable category: B for bisyllabic words lists and M for monosyllabic words lists and the list number with Arabic letters (e.g. 7_12.B.1 for the first list of bisyllabic words).

The speech audiometry was made in same conditions like PTA and results were stored in the database. Statistical analysis of data was performed using software package SPSS 20.0.

Results

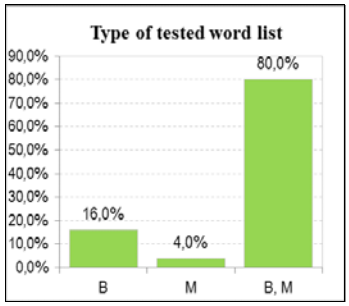
Descriptive analysis of the data indicated a relative homogenous group of study with 40% of boys and 60% of girls tested and having a balanced age distribution between 7 and 12 years with a mean of 9 years as shown in *Figure 1* (SD = 1.384).



a. b.

Figure 1. Descriptive analysis of the group:
a. Gender structure of the study group; b. Age distribution in the study group

As shown in *Figure 2a*, the majority of subjects of our group (80%) were tested with both bisyllabic and monosyllabic words lists, increasing the reliability of both categories of tested words, while 16% have been tested only with bisyllabic lists and 4% only with monosyllabic lists. The gender repartition of the group can be observed on the analysis of two categories of tested words lists (*Figure* 2.b), where the girls are slightly better represented than boys; in the test room the girls were more cooperative in terms of test duration.



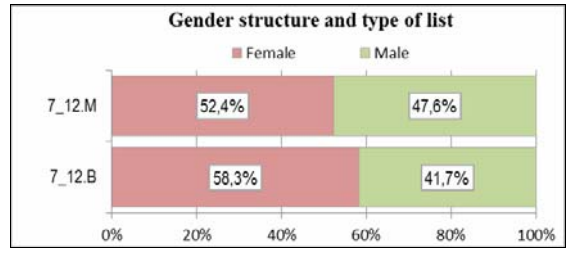


Figure 2a. Percent for every type of list tested by subjects: B – only bisyllabic words list, M – only monosyllabic words lists and B,M – bisyllabic and monosyllabic words lists; b. Gender distribution for the two type of list: : 7_12.B – bisyllabic lists and 7_12.M – monosyllabic lists

The statistical analysis of the main audiological parameters for the two types of words lists aimed to compare the mean PTA, SRT and MRT in the two lots, considering all tested ears equivalents as test units.

Figure 3 points for the bisyllabic tested lists a mean PTA of 13,11 dB HL for 4FAHL and 13,61 dB HL for 3FAHL with a mean SRT of 15,83 dB SPL corresponding to -4,17 dB HL and a mean MRT of 31,46 dB SPL corresponding to 11,46 dB HL.

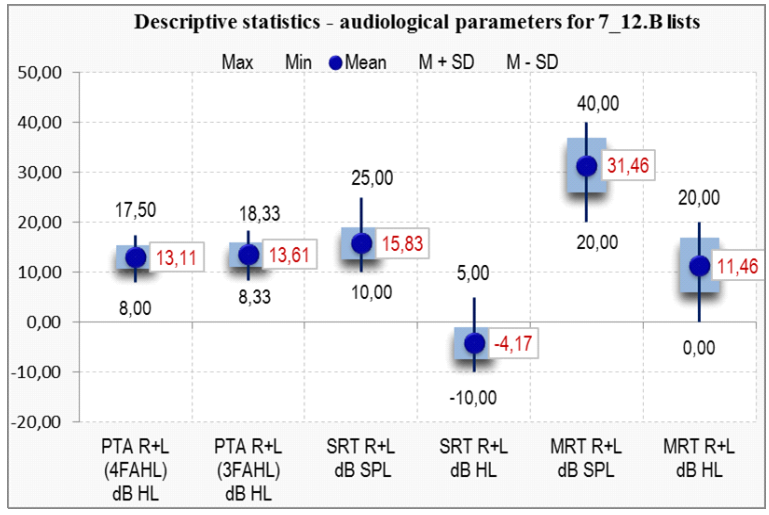


Figure 3. Descriptive statistics for 7_12.B lists – audiological parameters:

Note:

PTA R+L (4 FAHL) – Pure Tone Average for right and left ear - Four Frequency Average Hearing Level expressed in dB HL

PTA R+L (3 FAHL) – Pure Tone Average for right and left ear - Three Frequency Average Hearing Level expressed in dB HL

SRT R+L dB SPL – Speech Recognition threshold for right and left ear expressed in dB SPL

SRT R+L dB HL - Speech Recognition threshold for right and left ear expressed in dB HL

MRT R+L dB SPL – Maximum Recognition Threshold for right and left ear expressed in dB SPL

MRT R+L dB HL – Maximum Recognition Threshold for right and left ear expressed in dB HL

For the monosyllabic tested lists a mean PTA of 13.32 dB HL for 4FAHL and 13.92 dB HL for 3FAHL with a mean SRT of 17.50 dB SPL is corresponding to -2.50 dB HL and a mean MRT of 37.38 dB SPL corresponding to 17.38 dB HL.

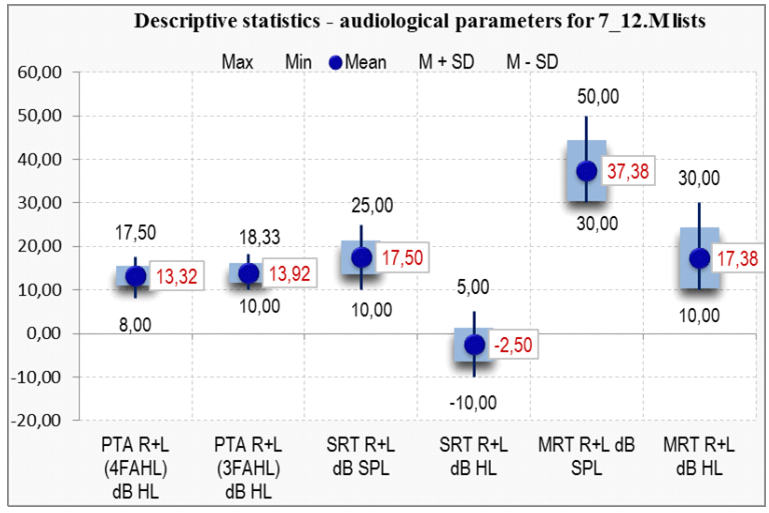


Figure 4. Descriptive statistics for 7_12.M lists –audiological parameters:

Note:

PTA R+L (4 FAHL) – Pure Tone Average for right and left ear - Four Frequency Average Hearing Level expressed in dB HL

PTA R+L (3 FAHL) – Pure Tone Average for right and left ear - Three Frequency Average Hearing Level expressed in dB HL

SRT R+L dB SPL – Speech Recognition threshold for right and left ear expressed in dB SPL

SRT R+L dB HL - Speech Recognition threshold for right and left ear expressed in dB HL

MRT R+L dB SPL – Maximum Recognition Threshold for right and left ear expressed in dB SPL

MRT R+L dB HL – Maximum Recognition Threshold for right and left ear expressed in dB HL

One of the most important and relevant audiological parameter is Word Recognition Score (WRS) for the 10 words lists for every tested intensity from 10 dB SPL to 100 dB SPL, with great importance for the 10 to 40 dB SPL in defining the shape of vocal audiogram. For every intensity there are represented the mean of WRS with standard deviation intervals and the maximum variation.

The *Figures* 5 and 6 highlights this parameter for bisyllabic and monosyllabic lists. It is easy to observe that the mean WRS riches over 95% at 30 dB SPL for both types of lists, starting with 40 dB SPL is constantly over 99% for all bigger intensities for bisyllabic lists and over 98% for monosyllabic lists, suggesting that the speech recognition is a little more difficult for monosyllabiCc words, in agreement with all well-known principles of speech recognition tests.

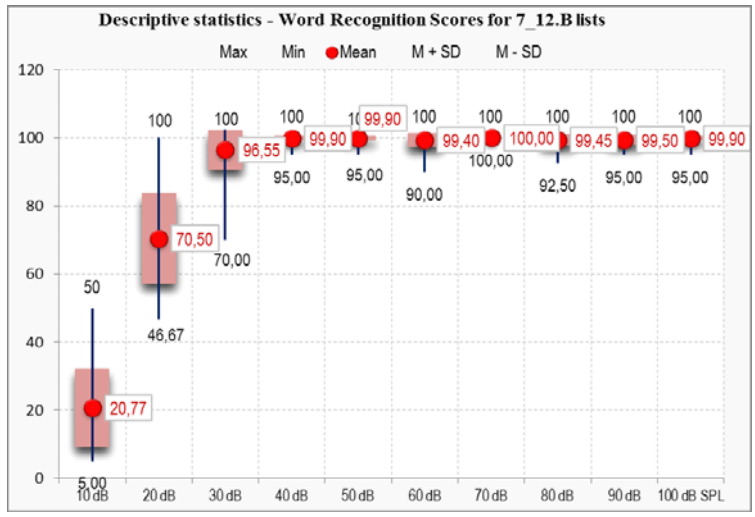


Figure 5. Descriptive statistics – percentage of recognized words for bisyllabic lists
Note: Abscissa – intensities - dB SPL Ordinate – Word Recognition Score (WRS) %

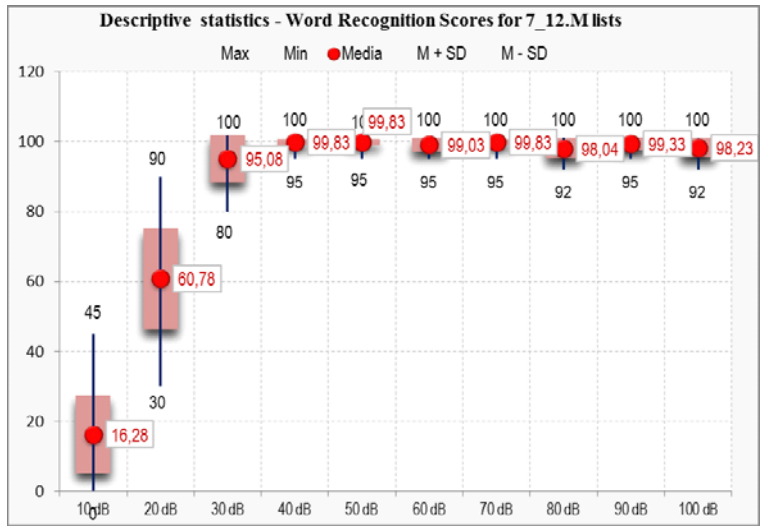


Figure 6. Descriptive statistics – percentage of recognized words for monosyllabic lists
Note: Abscissa – intensities - dB SPL Ordinate – Word Recognition Score (WRS) - %

The presentation of words at intensities between 10 and 30 dB SPL presents the most variable results for this group of age, suggesting a wider variability of whisper understanding in the population with normal tonal hearing. It was realized the percent distribution of all subjects according to Word Recognition Scores categories for the two groups of tested lists.

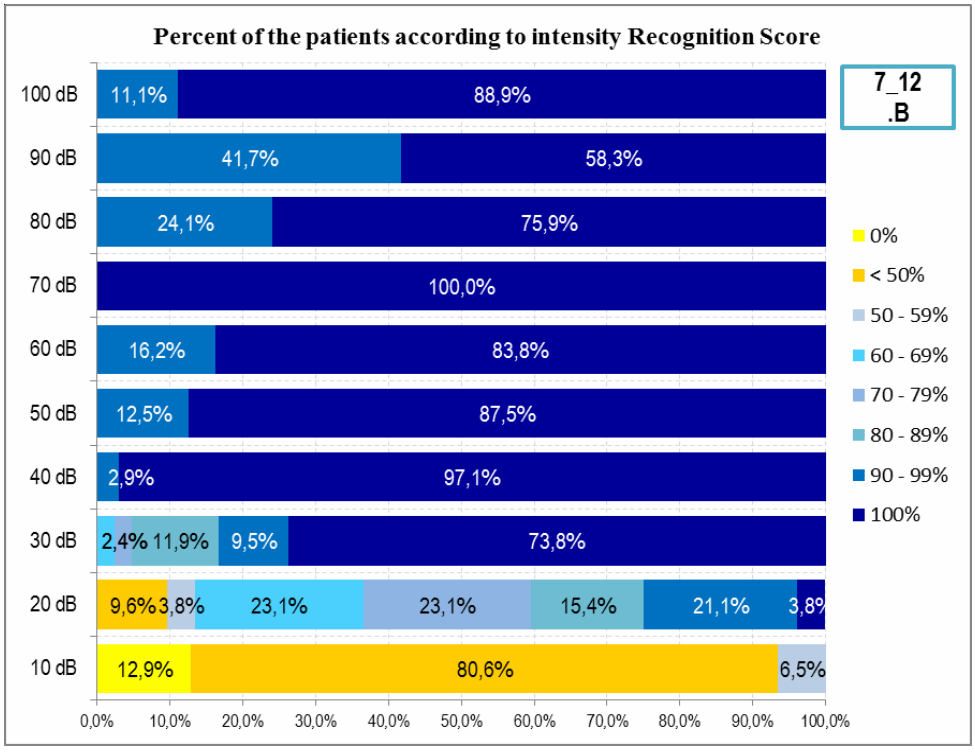


Figure 7. Percent of the patients according to Word Recognition Score for all intensities in bisyllabic words lists (7_12.B)

For bisyllabic lists presented at 30 dB SPL over 70% of children understood 100% of words (*Figure 7*) and at 40 dB SPL over 97% present 100% intelligibility. As the level of presentation increases we can note a tendency for decrease of intelligibility (less than 100%), but still rest for all subjects between 90 and 99%. Scores below 89% are shown only at intensity levels less than 30 dB SPL.

For monosyllabic lists (*Figure* 8) the intensity level of presentation had to exceed 40 dB SPL to achieve the majority of subjects with 100% intelligibility (over 78%) and the rest between 90 and 99% (21%). We note two differences between monosyllabic and bisyllabic lists: the maximum of speech performance is present at 30 dB SPL for bisyllabic lists and at 40 dB SPL for monosyllabic lists and the intelligibility decreases slightly more for monosyllabic lists at 100 dB SPL intensity.

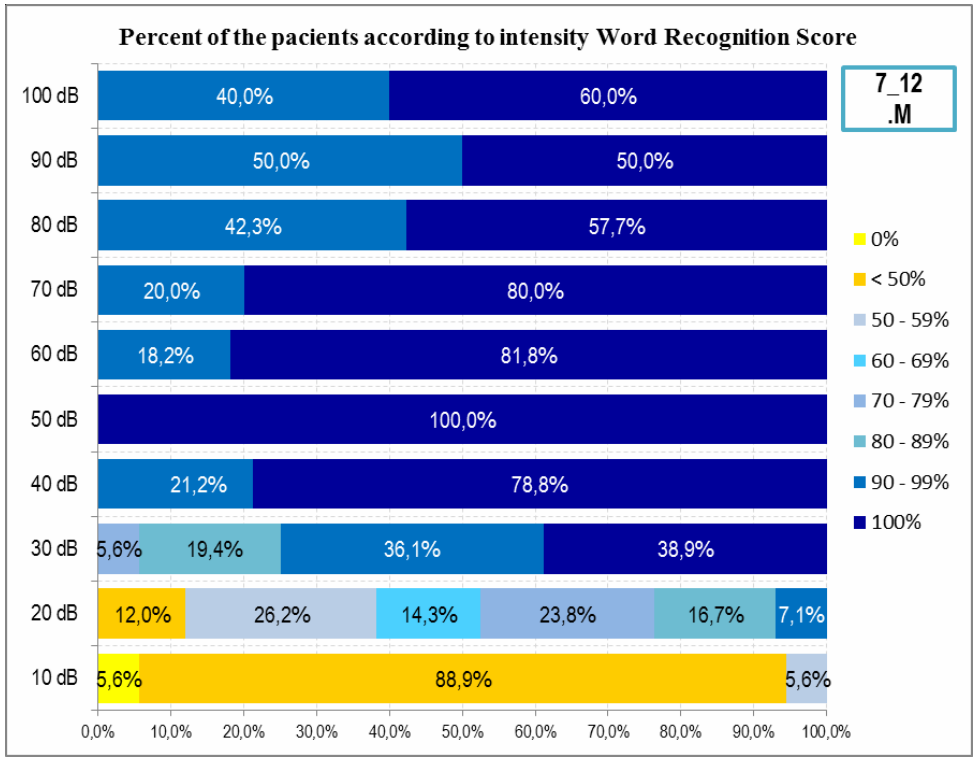


Figure 8. Percent of the patients according to Word Recognition Score for all intensities in monosyllabic words lists (7_12.M)

Discussions

The appropriate tests of speech perception performance in children should respect several criteria: the cognitive, motoric, and attentional demands of the test should be age-appropriate, performance should be independent of higher-level language abilities being appropriate to a linguistically common level, tests should ultimately assess a person's ability to communicate in everyday situations (Kosky & Boothroyd, 2003; Mendell, 2008). Creating a language corpus for primary school aged children based on early preschool education curriculum and primary school program approved by Ministry of Education and Scientific Research from Romania, we reached the goal of word familiarity and age-appropriate linguistic level. The absence of failure in speech recognition among the subjects as well as the absence of 100% for all children at more than 40 dB of presentation sustains the high quality of elaborated material.

The speech audiometry doesn't test only the intelligibility of the spoken words, but also the vocal production of the subject in the pronunciation performance. In

our study we showed that children aged between 7 and 12 years present for the bisyllabic tested lists a mean PTA of 13,11 dB HL for 4FAHL and 13,61 dB HL for 3FAHL with a mean SRT of 15,83 dB SPL corresponding to -4,17 dB HL and a mean MRT of 31,46 dB SPL corresponding to 11,46 dB HL. For the monosyllabic tested lists at a mean PTA of 13,32 dB HL for 4FAHL and 13,92 dB HL for 3FAHL we obtained a mean SRT of 17,50 dB SPL corresponding to -2,50 dB HL and a mean MRT of 37,38 dB SPL corresponding to 17,38 dB HL.

The results of tested lists for each subject as well as for entire group for monosyllabic words and also for bisyllabic words show parameters that fit with the normal vocal audiogram slope. The variability of the responses for normal hearing children for this group of age allows us to describe not just a regression line, but an area of the speech intelligibility audiogram that defines the normality (*Figures 5* and *Figure 6*). We consider that this extended area including all the responses would define better, in a more accurate manner, the normal vocal hearing instead of a single curve results from the mathematical statistics.

In many studies referring to the modality of digitally recorded speech audiometry material development for different languages, the audiological tests have been standardized with respect to audibility and psychometric function slope, being calculated for all words using logistic regression. Usually the selected words from different languages were digitally adjusted, to create word recognition lists which are relatively homogeneous with respect to audibility and psychometric slope. The methodology of developing the SRT materials was by selecting a subset of bisyllabic words with relatively steep psychometric function slopes and digitally equating their intensity to match the mean PTA of normally hearing subjects. We noticed in these studies the steepness of the shape of vocal audiogram, but as we mentioned before, we observed that a defined area of normal responses respects better than a regression line the variability of speech comprehension in the population of normal hearing children.

Any of audiometric slopes characterizing the speech recognition using these words lists and which is projected in the defined area of normality can be considered within normal limits for speech intelligibility. We also observed that in the exposed methodologies for audiometry material development the focus was to create lists primarily according to the criteria of familiarity and auditory homogeneity among lists without attempting to phonemically balance the word lists. It is generally recognized the extreme difficulty, if not impossibility, to simulate the frequency of phoneme occurrence in a language with a list containing a limited number of words. (Nissen *et al.,* 2011; Harris, *et al.,* 2007; Nissen, Harris & Slade, 2007). We realized phonetically balanced words list ensuring the test of subjects with the most common words of spoken language.

Once validated for normal hearing for 7-12 years old, the tests can be applied in the audiological assessment of hearing loss in children, to evaluate the speech

understanding for hearing aided or cochlear implanted children. Speech perception assessment in children is essential in child's progress over time and the audiologic test battery that we created could determine the type of necessary interventions (amplification, speech therapy) for language and communications skills improvements.

Conclusions

The aim of the study was accomplished showing that the material we created in order to test the speech intelligibility for children aged between 7 and 12 years is a clinical valid tool. This is the first Romanian clinical validated test respecting all auditory test standards in terms of the homogeneity of the material: frequency of the words in the spoken language – communality factor; balanced frequencies spectrum representation similar to frequencies spectrum of common spoken language; known words corresponding to speech and cognitive specific age development, according to national preschool and primary school education curriculum.

The originality of our work is that we realized phonetically balanced words list using our own and original algorithm ensuring the exposure of subjects to all frequencies spectrum of common Romanian spoken language. The study demonstrated that the tested material was homogenous; every single list of 10 words could be securely interchanged with any other one with the similar results in intelligibility performance. This is a very important characteristic parameter that such a material has to provide for a reliable result of the speech recognition test, any used list offering the same result for the same person and the same test intensity of stimulus presentation.

The material is comprehensive enough to provide a variability of the words in order to avoid a word repetition that could involve the cortical substitution based on the memorized previous presentation of the terms. Statistical analyses showed that for both bisyllabic and monosyllabic tests there are no significant statistically differences between results of different lists presentation for the same level of intensity among tested children. The results emphasize that the speech perception of the presented material is according to normality of normal hearing population.

The tests we developed represent an important validated tool to be used for assessment of hearing and communication common disorders as well as for other special hearing pathological conditions as auditory neuropathy spectrum disorders, neurological diseases or associated comorbidities with normal or subnormal tonal hearing and inappropriate speech recognition and production.

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