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# Asimetry in tone-hearing threshold and speech detection threshold in the left and right ear among children with speech and language disorders

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**Abstract:**This paper analyses the middle values of tone-hearing threshold and speech detection threshold in the left and right ear among children with speech and language disorders (n = 60) and among children with normal speech and language development (n = 30). The sample included children of both genders between the ages of 5 and 7. Tone-hearing threshold testing was performed using Maico tonal audiometer, and speech detection threshold testing was done using KSAFA-m device. The results showed that the children with speech and language disorders have a somewhat better hearing threshold in the left ear compared with the right, but this result was not statistically significant. Contrary to this result, a statistically significant superiority of the right ear related to the hearing threshold at the frequencies of 0,125 kHz and 4 kHz was noted among the children with normal speech and language development. A statistically significant superiority of the left ear related to the speech detection threshold at 0,125 kHz was noted among the children with speech and language disorders. A slight superiority of the left ear was noted among the children with normal speech and language development, but without statistical significance. Comparison of asymmetry results between left and right ear (hearing threshold in the left and right ears) showed that the children with normal speech and language development have statistically more significant asymmetry than the children with speech and language disorders at 0,125kHz, 4kHz, 6kHz when considering the overall results. Based on these results, it can be concluded that the children with speech and language disorders in comparison to the children with normal speech and language development: have worse tone-hearing threshold and speech detection threshold in both left and right ear, show better results in the left ear and have less pronounced asymmetry of the left and right ear in hearing threshold.
*Keywords***:** hearing threshold, speech detection threshold, speech and language disorder, asymmetry

## 1 Introductory considerations

Auditory perception is the ability to subjectively experience a particular acoustic stimulus that can be different (tone, murmur, noise, speech). Auditory perception and memory imply the procedure which consists of receiving, processing and storing auditory stimuli. The sense of hearing is a requisite for the precise speech perception. Its role begins in the prenatal period, and it fully develops a few years after the birth. The process of auditory perception includes four basic stages:

**(1)** The first stage consists ofthe mechanical transfer of acoustic stimulation to sensory cells in the cochlea.

**(2)** The second stage encompasses the conversion of a mechanical sound stimulus into a sensory stimulus, i.e. the transformation of the energy from one form to another.

**(3)** The third stage includes the transmission of electrical impulses through the hearing nerve to the brain.

**(4)** The fourth stage implies the psychoacoustic and psycholinguistic level of listening. The conscious processing of the sound stimulus takes place during this stage, i.e. the decoding of acoustic information (Ostojić, 2004).

An absolute threshold of sensitivity is a minimal stimulus required for the appearance of a barely noticeable sensation. The lower auditory threshold is an auditory stimulus of a minimal energy sufficient to register a barely noticeable sound. The upper threshold is the highest intensity of a stimulus which is being differentiated. The sensation does not change with the further increase of the intensity. The upper threshold is an intensity of the auditory stimulus which does not change the awareness of sound level by thefurther increase. The differential threshold is the smallest change of the auditory stimulus intensity whichnecessarilyleads to the first change in perception of the above-mentionedintensity (Brajović, 1997).

Binaural perception is based on the perception of differences between signals (stimuli) delivered to the left and right ear. In the acoustic environment, these differences occur due to various sound propagation paths from the source of the sound to the ears of the listener. These differences occur due to the influence of the listener's body, head, and earlobe, as well as other objects in the environment, and with the help of these factors, people are able to locate the sound source in space or perform a useful detection of sound in the environment full of different sources of interference (Durlach, Colbrun, 1978, Jovičić, 1999).

When it comes to the threshold of audibility, its value is lower in binaural than inmonaural listening conditions. Differences between the levels of monaural and binaural stimulus are defined by the advantage of binaural listening. Minimal interaural differences are defined as the interaural sensitivity (or resolution). The most important interaural differences are found in the interauralamplitude, phase, and time differences, in the interaural correlations, as well as in spatial interaural differences related to the localization of the sound source (Jovičić, 1999).

Asymmetries in the audiogram can lead to diagnostic and procedural uncertainties in the practice of otology and audiology. Clearly, this phenomenon is evident when a disorder of the middle ear and conductive hearing loss are present. A probable reason for the asymmetry can also be asensorineural hearing loss, which is caused by head injury or a nearby explosion. This can lead to a severe unilateral damage. In situations in which there is no obvious cause, further analysis should be performed in order to check the existence of the more serious conditions, such as vestibular schwannoma. The American and British procedures rely on this information in deciding whether patients should seek otologic opinion. These facts raise the question: In what extent can asymmetry be considered physiological? Minimal asymmetries can simply arise as a result of the audiometer's inaccuracy when the test-retest difference from 5 to 10 dB is a common occurrence (Lutman, Coles, 2009).

Findings that show the pure-tone hearing threshold is, on average, weaker in the left than in the right ear, particularly in the frequency range from 3 to 6 kHz, cause confusion among the researchers since broad-bandwidth questionnaires (surveys, tests) became available. Although the statistical significance related to poorer hearing in the left ear was not considered in most studies of this type, it can be noted that hearing in the left ear, particularly among adult males, is 2 to 4 dB lower than in the right ear. A similar, but milder effect is also noted among women who are exposed to noise. Among children, this asymmetry is minimal. (Pirilä, Jounio-Ervasti & Surri, 1992).

## 2 Aim of the paper

The aim of this paper is to determine whether there is an asymmetry between left and right ear among children with speech and language disorder, based on measuring pure-tone hearing threshold and speech detection threshold. Also, this paper compares the results of the children with speech and language disorder and children with normal speech and language development, with an aim to establish whether there are certain differences between these two groups.

## 3 Research methods

The research was planned and carried out in a way that ensured the collection of statistically representative data. The research took place at the Institute for experimental phonetics and speech pathology and Defectology-speech and language cabinet "Plećević" in Belgrade.

The sample included 60 children with speech and language disorders and 30 children with normal speech and language development between the ages of 5 and 7. The average age of children with speech and language disorders expressed in months was 72,8 months, while the average age of children with normal speech and language development was 74,8 months. Fundamental anamnestic data was taken from the medical records of the subjectswith the prior consent of the responsible people in the institutions where the research took place, as well as the subjects' parents. Forming criteria for the group of subjects with speech and language disorders included: thepresence of speech and language disorder, exclusion of hearing impairment and average intellectual ability. Forming criteria for the group of children with normal speech and language development were: normal development of speech and language skills, exclusion of hearing impairment and average intellectual ability. The group of children with speech and language disorders consisted of 38 boys (63,33%) and 22 girls (36,67%), while the group of children with normal speech and language development included 15 boys (50%) and 15 girls (50%). Distribution of the subjects according to gender in the group of children with speech and language disorders reflects the real relation between boys and girls in different aspects of speech and language disorders.

In order to carry out an adequate examination of the observed children's abilities, the following instruments and techniques were used: tonal liminal audiometry and ksafametry.

Tonal audiometry is a hearing measurement technique during which the subject actively cooperates with the examiner, by giving him a sign when he hears the tone.This method is not the best choice for examining auditory perception among children at the earliest age, i.e. under three years of age. Tonal audiometry is usually used with children older than three,because they are able to understand the requirements necessary for the implementation of this procedure. The aim of audiometry is to find the lowest intensity of a stimulus sufficient to evoke the first, barely noticeable sensation, i.e. lower limit or liminal threshold (Brajović, 1986).

This type of measurement is performed using an audiometer. It is necessary that the device has certain characteristics that provide adequate conditions for airborne and bone conduction of sound to the subject's ear. The device should be calibrated and it is required that the examiner is well aware of the test procedure and techniques. The essence of tonal audiometry is the examination of airborne and bone tonal perception. The examiner plays tones of a certain frequency and decibel level, and the subject is asked to show a sign upon hearing the tone. During the hearing tests, if the errors are greater than 10 to 15 dB, it is acceptable to suspect the correct operation of the device, or an insufficient engagement of the subjects or examiners. The difference from 5 to 10 dB is considered to be acceptable.

For the reception of voice messages, the most important frequency range is from 500 to 4000Hz, therefore Fowler-Sabin (Brajović, 1982) suggest that hearing assessment should be performed based on the average decibel level in the frequency range from 500, 1000, 2000 and 4000Hz. Tone hearing threshold testing was performed using MAICO-MA 53 tonal audiometer.

Ksafametry is a specialized diagnostic hearing test which is performed using KSAFA-mdevice and it determines the hearing threshold, that is, detects the complex signal. Ksafametry differs from speech audiometry because the subjects are not required to understand and repeat words. The stimulus that is used in ksafametry is *1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 100, 1000,* or *nice*, and its choice was based on the phonological analysis and acoustic structure of sounds in the Serbian language.

KSAFA method and KSAFA-m device are based on the division of speech spectrum into a larger number of frequency bands, and their parameters can be changed if desired. This makes speech perception possible and makes maximal use of child's hearing potential.

By using KSAFA-m device, it is also possible to examine detection of the speech signal in the frequency range predicted for examination of tonal perception by using tonal audiometry. For the purposes of our research, we made use of this particular feature of KSAFA-m device. Therefore, it is possible to compare the values obtained by means of tonal audiometry with the values obtained by means of ksafametry.

The results were statistically processed using the following methods: descriptive statistics and t-tests.

## 4 Research results

### 4.1Tone hearing thresholds and asymmetries

Table 1 shows the results of tone hearing thresholds for each ear (right-left) among children with speech and language disorders (CSLD) and children with normal speech and language development (CNSLD). Among CSLD, the worst hearing thresholds were detected in the low-frequency range from 0, 125 to 1kHz, and in the high-frequency range from 6 to 8kHz. Somewhat better results were recorded among CSLD in the frequencyof 2 and 4kHz. Children with normal speech and language development, unlike children with speech and language disorders, showed better hearing threshold results in the right earin most frequency ranges, except in the frequency 1 and 8kHz. In addition, it is noted that hearing thresholds were also the worst in the low-frequency range from 0,125 to 0,500kHz among these children, but unlike CSLD, thresholds in the middle and high range were approximately similar. Among both groups of children, the worst perceived frequency was 0,125kHz. CSLD best heard the frequency of 4kHz and CNSLD the frequency of 6kHz. Statistically significant differences in pure-tone thresholds between left and right ear occurred only among CNSLD at the frequencies of 0,125 and 4 kHz (Table 1).

**Table 1.** Hearing threshold level in the right and left ear among children with speech and language disorders (CSLD) and children with normal speech and language development (CNSLD)

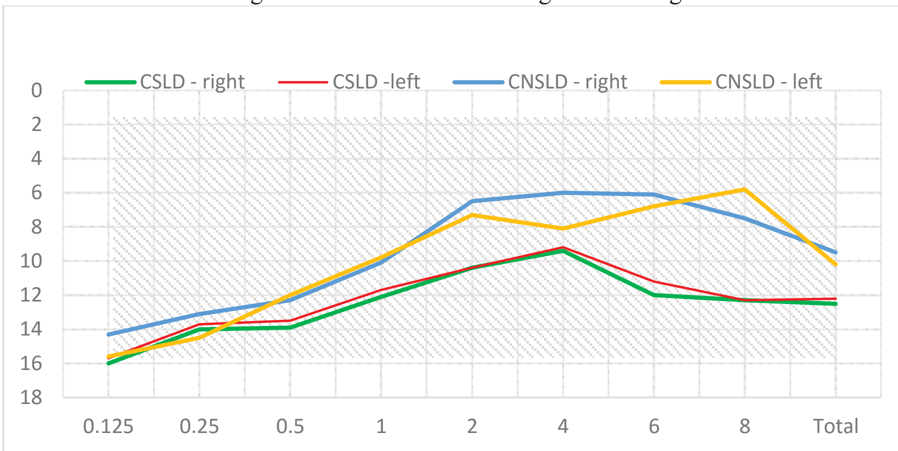
| | CSLD | | | CNSLD | | |
|---|---|---|---|---|---|---|
| Frequency kHz | Right | Left | p< | Right | Left | p< |
| 0.125 | 16,0 | **15,7** | | **14.3** | 15.6 | 0.017 |
| 0.250 | 14,0 | **13,7** | | **13.1** | 14.5 | |
| 0.500 | 13,9 | **13,5** | | 12.3 | **12.0** | |
| 1 | 12,1 | **11,7** | | 10.1 | **9.8** | |
| 2 | 10,4 | **10,4** | | **6.5** | 7.3 | |
| 4 | 9,4 | **9,2** | | **6.0** | 8.1 | 0.010 |
| 6 | 12,0 | **11,2** | | **6.1** | 6.8 | |
| 8 | 12,3 | **12,3** | | 7.5 | **5.8** | |
| Average | 12,5 | **12,2** | | **9.5** | 10.2 | |

Comparison ofthe hearing thresholds for the right ear between CSLD and CNSLD, showed that there is a statistically significant difference in most of the tested frequencies ($p<0,05$), except in the low ones, i.e. at 0,125 and 0,500 kHz (Table 2). Statistically significant differences are noticed in the left ear at the frequencies of 0,500, 1 and 6 kHz, and also taking the complete results into consideration ($p<0,05$).On the basis of this data, it can be concluded that the results recorded among CNSLD showed better statistical significance for the pure-tone hearing thresholds in the right ear, and in the left ear only at individual frequencies (Table 2, Chart 1).

**Table 2.** Statistical significance for the hearing threshold differences in the left and right ear between children with speech and language disorders (CSLD) and children with normal speech and language development (CNSLD)

| Frequency kHz | Right | | | Left | | |
|---|---|---|---|---|---|---|
| CSLD - CNSLD | Mean | SD | p< | Mean | SD | p< |
| 0.125 | 0,3 | 7.3 | | 2.3 | 7.1 | |
| 0.250 | 2.3 | 7.9 | | 2.6 | 7.5 | |
| 0.500 | 4.0 | 7.4 | 0,003 | 5.5 | 9.2 | 0,007 |
| 1 | 4.3 | 8.6 | 0,001 | 6.0 | 8.5 | 0,011 |
| 2 | 1.3 | 8.8 | 0,008 | 4.6 | 8.9 | |
| 4 | 1.0 | 10.4 | 0,018 | 3.6 | 7.9 | |
| 6 | 5.1 | 9.6 | 0,005 | 5.5 | 9.8 | 0,007 |
| 8 | 2.1 | 8.6 | 0,034 | 3.3 | 8.1 | |
| Average | 7.3 | 4.8 | 0,000 | 8.3 | 4.6 | 0,000 |

**Chart 1.** Tone-hearing thresholds in the left and right ear among CSLD and CNSLD




The results of asymmetry were simply calculated by subtracting right ear hearing thresholds from left ear hearing thresholds. The sign in front of the number indicates the ear with a worse hearing threshold. If the sign is (+), it means that the hearing threshold is worse in the right ear, and if the sign is (-), it means that the hearing threshold is worse in the left ear (Table 3). Among CSLD, the asymmetries were not pronounced and they ranged from 0 to +0,8 dB. The highest average asymmetry was noted at 6 kHz, and no asymmetries were detected at the frequencies of 2 and 8 kHz. Among CNSLD, the asymmetries were significantly more pronounced, and they were present at all tested frequencies, ranged from -3 to +0,3 dB. The highest asymmetries were detected at the frequencies of 0,125 kHz -3 dB and 4 kHz -2,1 dB. The least average asymmetries were noted at 0,500 and 1 kHz +0,3dB.Comparison of the asymmetries between CSLD and CNSLD provided the results which show that there are statistically more pronounced asymmetries among CNSLD at the frequencies of 0,125, 4, and 6 kHz, compared to CSLD, since p-valueis ≤ 0,050. Also, in the total average results of the asymmetry, the results among CNSLD were statistically more significant (Table 3).

**Table 3.** Statistical significance of the differences between right-left ear (asymmetry) among children with speech and language disorders (CSLD) and children with normal speech and language development (CNSLD).

| Frequency kHz | CSLD | | CNSLD | | |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | p< |
| 0.125 | +0,4 | 4,0 | -3,0 | 6,5 | 0,008 |
| 0.250 | +0,3 | 4,8 | -1,4 | 5,2 | |
| 0.500 | +0,4 | 4,8 | +0,3 | 4,5 | |
| 1 | +0,4 | 5,7 | +0,3 | 4,9 | |
| 2 | 0,0 | 4,0 | -0,8 | 4,3 | |
| 4 | +0,2 | 6,6 | -2,1 | 4,2 | 0,009 |
| 6 | +0,8 | 6,3 | -0,7 | 5,8 | 0,050 |
| 8 | 0,0 | 6,2 | +1,7 | 5,4 | |
| Average | +0,3 | 2,8 | -0,7 | 2,9 | 0,014 |

### 4.2 Speech detection threshold and asymmetry

Table 4 shows the results of speech detection thresholds among CSLD and CNSLD in the left and right ear. CSLD showed better speech detection threshold in the left ear, while CNSLD had an approximately similar distribution of better speech detection threshold results in the left and right ear. The distribution of better speech detection thresholds at certain frequencies among both CSLD and CNSLD was very similar to the distribution of pure-tone hearing thresholds. Among CSLD, at all frequencies, speech detection threshold was better in the left ear, except at 0,125 and 6 kHz. Among

CNSLD, at the frequency of 0,125, 1 and 8 kHz, speech detection thresholds were better in the right, and at other frequencies in the left ear (Table 4). Statistically significant differences in speech detection thresholds between right and left ear occurred only among CSLD at the frequency of 0,125 kHz (Table 4).

**Table 4.** Speech detection threshold levels in the right and left ear among children with speech and language disorders (CSLD) and children with normal speech and language development (CNSLD)

| | CSLD | | | CNSLD | | |
|---|---|---|---|---|---|---|
| Frequency kHz | Right | Left | p< | Right | Left | p< |
| 0.125 | **16.4** | 18.1 | 0.003 | **12.6** | 13.5 | |
| 0.250 | 16.8 | **16.3** | | 11.3 | **10.0** | |
| 0.500 | 15.9 | **15.0** | | 10.3 | **9.3** | |
| 1 | 15.2 | **14.5** | | **8.8** | 9.6 | |
| 2 | 14.6 | **14.1** | | 10.1 | 10.1 | |
| 4 | 14.3 | **13.6** | | 11.0 | **9.6** | |
| 6 | **15.5** | 15.7 | | 9.5 | **8.5** | |
| 8 | 15.5 | **14.6** | | **8.5** | 9.5 | |
| Average | 15.5 | **15.3** | | 10.2 | **10.0** | |

Comparison of the speech detection thresholds in the right ear between CSLD and CNSLD shows that there is a statistically significant difference at the level p=0,000, at all tested frequencies (Table 5). CNSLD showed better statistical significance for the speech detection thresholds in the right ear, at all tested frequencies. The almost identical result was obtained in the left ear, the difference is only in the value of p, which is $p \leq 0{,}001$. On the basis of this, it can be concluded that children with normal speech and language development show better, statistically significant results in speech detection than children with speech and language disorders (Table 5, Chart 2).

**Table 5.** Statistical significance of the differences in speech detection thresholds in the left and right ear among children with speech and language disorders (CSLD) and children with normal speech and language development (CNSLD)

| Frequency kHz | Right | | | Left | | |
|---|---|---|---|---|---|---|
| CSLD-CNSLD | Mean | SD | p< | Mean | SD | p< |
| 0.125 | -5.1 | 7.8 | 0,000 | -5.0 | 6.2 | 0,001 |
| 0.250 | -6.8 | 7.8 | 0,000 | -7.8 | 6.9 | 0,000 |
| 0.500 | -7.1 | 6.9 | 0,000 | -6.5 | 9.0 | 0,000 |
| 1 | -7.6 | 8.2 | 0,000 | -5.8 | 5.8 | 0,000 |
| 2 | -5.6 | 6.7 | 0,000 | -4.5 | 5.6 | 0,000 |
| 4 | -3.6 | 5.5 | 0,000 | -4.5 | 6.0 | 0,001 |
| 6 | -7.6 | 5.6 | 0,000 | -6.6 | 6.0 | 0,000 |
| 8 | -8.0 | 6.1 | 0,000 | -5.3 | 5.7 | 0,000 |
| Average | -6.4 | 4.5 | 0,000 | -5.7 | 4.4 | 0,000 |

**Chart 2.** Speech detection thresholds among CSLD and CNSLD in the left and right ear

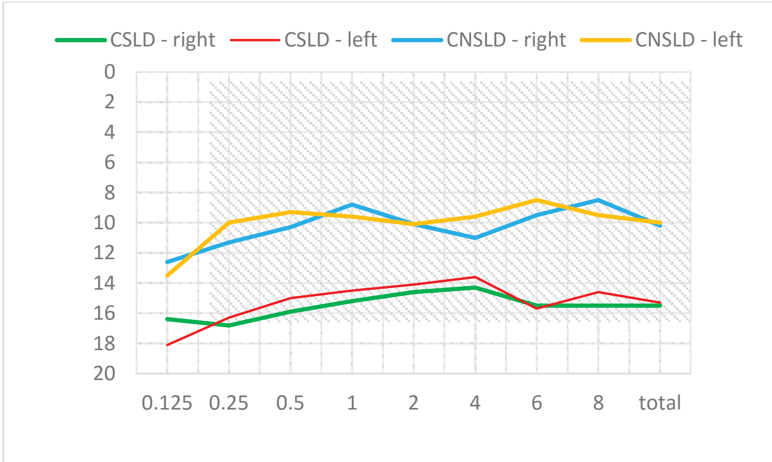



**Table 6.** Statistical significance of the differences between right-left ear (asymmetry) among CSLD and CNSLD in speech detection thresholds

| Frequency kHz | CSLD | | CNSLD | | |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | p< |
| 0.125 | -1,7 | 4.3 | -0,9 | 6.5 | |
| 0.250 | +0,5 | 5.3 | +2,3 | 5.4 | |
| 0.500 | +0,9 | 5.7 | +1,0 | 4.2 | |
| 1 | +0,7 | 5.5 | -0,8 | 3.4 | |
| 2 | +0,5 | 5.6 | 0,0 | 3.9 | |
| 4 | +0,7 | 6.5 | +1,4 | 3.9 | |
| 6 | -0,2 | 5.6 | -1,0 | 3.8 | |
| 8 | +0,9 | 5.6 | -1,0 | 3.0 | 0,018 |
| Average | +0,7 | 2.9 | +1,05 | 2.3 | |

Unlike the asymmetry found in pure-tone hearing thresholds, which showed a lot of statistically significant differences between CSLD and CNSLD, there was not a lot of such differences in speech detection thresholds. When it comes to the asymmetries of speech detection thresholds, a statistically significant difference was found only at the frequency of 8 kHz (Table 6). The asymmetries among CSLD ranged from -1,7 to +0,9 dB, and among CNSLD from +2,3 to -0,9 dB. Although CNSLD had more pronounced asymmetries of speech detection thresholds than CSLD, those were not statistically significant (Table 6).

#### 4.3 Comparison between tone-hearing thresholds and speech detection thresholds

**Table 7.** Statistical significance of the differences between tone-hearing thresholds and speech detection thresholds in the left and right ear among children with speech and language disorders (CSLD)

| Frequency kHz | Right | | | Left | | |
|---|---|---|---|---|---|---|
| CSLD | Mean | SD | p< | Mean | SD | p< |
| 0.125 | -0,3 | 7,4 | | -2,5 | 5,6 | 0,001 |
| 0.250 | -2,7 | 7,7 | 0,008 | -2,5 | 6,6 | 0,004 |
| 0.500 | -2,0 | 6,7 | 0,026 | -1,5 | 7,4 | |
| 1 | -3,2 | 7,3 | 0,001 | -2,8 | 6,6 | 0,002 |
| 2 | -4,2 | 7,2 | 0,000 | -3,7 | 6,6 | 0,000 |
| 4 | -4,9 | 7,6 | 0,000 | -4,4 | 8,6 | 0,000 |
| 6 | -3,4 | 7,1 | 0,000 | -4,5 | 8,2 | 0,000 |
| 8 | -3,2 | 8,1 | 0,003 | -2,3 | 8,0 | 0,029 |
| Average | -3,0 | 5,3 | 0,000 | -3,0 | 4,8 | 0,000 |

CSLD showed better tone-hearing thresholds than speech detection thresholds at all tested frequencies in both ears (Table 7). The differences between tone-hearing thresholds and speech detection thresholds detected in the right ear ranged from -0,3 to -4,9 dB, and in the left ear from -4,5 to -1,5 dB. Statistically significant differences were found at all frequencies, except at 0,500 kHz in the left ear. It can be concluded that children with speech and language disorders have better tone-hearing thresholds than speech detection thresholds both in the left and the right ear.

**Table 8.** Statistical significance of the differences in asymmetries between tone-hearing thresholds and speech detection thresholds among children with speech and language disorders (CSLD)

| Frequency kHz | Asymmetry between tone-hearing threshold and speech detection threshold | | |
|---|---|---|---|
| | Mean | SD | p< |
| 0.125 | -1,3 | 6,0 | |
| 0.250 | -0,3 | 8,6 | |
| 0.500 | 0,1 | 7,0 | |
| 1 | 0,1 | 7,8 | |
| 2 | 0,0 | 7,3 | |
| 4 | -1,5 | 8,3 | |
| 6 | 0,0 | 8,7 | |
| 8 | 1,1 | 8,3 | |
| Average | -0,2 | 4,0 | |

Table 8 shows the differences in asymmetries between pure-tone hearing thresholds and speech detection thresholds among CSLD. At the frequencies of 0,125, 0,250, 4 kHz the differences in asymmetries were bigger in tone-hearing thresholds. At all the other frequencies, the differences were bigger in speech detection thresholds. The biggest difference between these thresholds was detected at 0,125 and 4 kHz. Statistical analysis showed that the difference between asymmetries in tone-hearing thresholds and speech detection thresholds was not statistically significant at any frequency among CSLD (Table 8).

**Table 9.** Statistical significance of the differences between tone-hearing thresholds and speech detection thresholds in the left and right ear among children with normal speech and language development (CNSLD)

| Frequency kHz | Right | | | Left | | |
|---|---|---|---|---|---|---|
| CNSLD | Mean | SD | p< | Mean | SD | p< |
| 0.125 | +1,6 | 7,2 | | +3,8 | 7,8 | 0,012 |
| 0.250 | +1,8 | 4,9 | | +4,5 | 6,6 | 0,001 |
| 0.500 | +2,0 | 4,2 | 0,016 | +2,6 | 6,6 | 0,036 |
| 1 | +1,3 | 4,9 | | +0,1 | 6,0 | |
| 2 | -3,6 | 5,2 | 0,001 | -2,8 | 5,2 | 0,006 |
| 4 | -5,0 | 5,5 | 0,000 | -1,5 | 6,0 | |
| 6 | -3,3 | 6,7 | 0,011 | -1,6 | 7,3 | |
| 8 | -1,0 | 6,2 | | -3,6 | 7,4 | 0,011 |
| Average | -0,7 | 4,0 | | +0,1 | 4,7 | |

Unlike CSLD, who exclusively showed better pure-tone hearing thresholds, CNSLD had mixed results (Table 9). Both on the left and the right ear, from low to partially mid-range frequencies, that is, at the frequency of 0,125, 0,250, 0,500 and 1 kHz, children with normal speech and language development (CNSLD) had better speech detection thresholds than pure-tone hearing thresholds. At other frequencies, this group of children better perceived pure-tone than speech. The differences between pure-tone hearing thresholds in the right ear ranged from -5 to +2 dB, and in the left ear from +4,5 to -3,6 dB. Statistically significant differences occurred in the right ear at the frequencies of 0,500, 2, 4 and 6 kHz (p<0,050), and in the left ear at 0,125, 0,250, 0,500. 2 and 8 kHz (p<0,050) (Table 9).

**Table 10.** Statistical significance of the differences in asymmetries between tone-hearing thresholds and speech detection thresholds among children with normal speech and language development (CNSLD)

| Frequency kHz | Asymmetry between tone-hearing threshold and speech detection threshold | | |
|---|---|---|---|
| | Mean | SD | p< |
| 0.125 | +2,1 | 7,8 | |
| 0.250 | +2,6 | 7,0 | 0,047 |
| 0.500 | +0,6 | 6,6 | |
| 1 | -1,1 | 6,2 | |
| 2 | +0,8 | 6,0 | |
| 4 | +3,5 | 5,2 | 0,001 |
| 6 | +1,6 | 6,4 | |
| 8 | -2,6 | 6,5 | 0,033 |
| Average | +0,9 | 3,5 | |

Table 10 shows the results of differences in asymmetry for tone-hearing thresholds and speech detection thresholds among children with normal speech and language development. At 0,125, 0,250, 0,500, 2, 4 and 6 kHz, the differences in asymmetry were bigger for tone-hearing thresholds than for speech detection thresholds. The differences ranged from +2,6 to -2,6 dB. The biggest difference was detected at 0,250 and 8 kHz (Table 10). Statistically significant differences were found in asymmetries at 0,250, 4 and 6 kHz among CNSLD (Table 10).

## 5. Discussion

The results obtained from this research in relation to better tone-hearing thresholds in the right ear among children with normal speech and language development correspond with the ones found in similar studies. (Pirilä, Jounio-Ervasti&Sorri, 1992; Chung, Mason, Gannon &Willson, 1983;

Axelsson& Lindgren, 1981; Roberts & Huber, 1970; Đoković, Slavnić&Ostojić, 2003). Statistically significant differences in favor of the right ear at the frequency of 4 kHz were found in the abovementioned studies, which was also confirmed in this research. Statistically significant difference in pure-tone thresholds was found at the frequency of 0,125 kHz, among children with normal speech and language development. Unlike them, children with speech and language disorders showed better tone-hearing threshold in the left ear, which confirmed the results obtained in similar research papers (Maksimović, 2011; Pantelić, 2010; Plećević, 2007).

Speaking of the results in relation to speech detection thresholds among children with speech and language disorders, it can be stated that they are similar to the tone-hearing threshold results. Namely, among these children, better results were detected in the left ear in most of the tested frequencies. Slightly different results were recorded among children with normal speech and language development in comparison to tone-hearing thresholds. Among these children, the right ear was not as dominant as in the tone-hearing thresholds, and the results indicated consistency in the distribution of better speech detection thresholds, both in the left and the right ear. It should be pointed out that there were no statistically significant differences between right and left ear among children with normal speech and language development.

The results gained from this research point to better tone-hearing thresholds and speech detection thresholds in the left ear among children with speech and language disorders.This cansomewhat explain the difficulties that arise in the auditory processing of their speech. It is a well-known fact that a sensation which comes from one side of the body is controlled by the opposite side of the brain. Information gained from the right ear is directly transmitted to the left hemisphere which is responsible for speech and language. This does not mean that information that comes from the left ear can't be used for speech and language understanding because the two hemispheres communicate with one another and they are connected by the structure named corpus callosum. Left and right hemispheres are not entirely separated entities and they cooperate with one another. However, the information derived from the left ear must be first transmitted from the right hemisphere to the language area of the left hemisphere, in order to be processed. This results in somewhat longer neural processing of language if speech or sounds are received through the left ear. This could explain, above all, prolonged reactions and responses of children with speech and language disorders in relation to verbal or other audio tasks.

Statistically significant differences were recorded by comparing the results of tone-hearing threshold in the left and right ear between CSLD and CNSLD. Children with normal speech and language development had better tone-hearing thresholds in mid-range and high-frequency ranges in both ears compared to children with speech and language disorders, while statistic difference was not detected in low frequencies. Similar results were found in other studies, such as the one conducted by Pantelić (2010; 2011) and Bishop (1999). However, their results were not statistically significant. Another research that was also carried out on children with speech and language disorders showed a statistically significant difference in hearing thresholds compared to children with normal speech and language development (Plećević, 2007).

The results of comparing speech detection thresholds between CSLD and CNSLD indicate that children with normal speech and language development show statistically better results than children with speech and language disorders at all tested frequencies. On the basis of this, it can be concluded that bigger differences occur between these two groups of children in speech than in tone perception. This would mean that acoustic complexity or a type of sound phenomenon affects the perception among CSLD. In addition, this result could be interpreted as a weaker specialization of the receptor cells in the cochlea for the reception and transmission of the voice signal among CSLD.

Asymmetries of tone-hearing thresholds between right and left ear are present in both groups of children, but they are more pronounced among children with normal speech and language development. Statistically significant differences in asymmetries were detected at the frequencies of 0,125, 4, 6 kHz and taking into consideration the overall results. Asymmetries in speech detection thresholds were neither much pronounced among CSLD nor among CNSLD. But even considering these results, the asymmetries were more pronounced among children with normal speech and language development. Statistically significant differences occurred only at the frequency of 8 kHz. These results indicate that children with speech and language disorders who have worse tone-hearing and speech detection thresholds, show less pronounced asymmetry. One of the explanations for this phenomenon is given by Chung et al. (1983). They noticed that an average ear asymmetry, "the ear effect", first increases as a function of thehearing threshold level, but it begins to decrease when hearing threshold reaches the level of 30 to 50 dB (Chung et al., 1983). This research did not show a continuous increase of the asymmetry with thedeterioration of hearing threshold, and particularly not upon measuring speech detection thresholds. Larger asymmetries were detected in some better hearing thresholds than in the worse ones. In particular, this explanation could not be applied to the group of children with normal speech and language development. Pirilä et al. (1992) had a different view about this matter and theypaid more attention to the methodological explanation in the consideration of asymmetry. They point to the lack of analysis in relation to the average asymmetry of the left and right ear and direct attention to the importance of observing anasymmetry in the individual hearing thresholds. When the average thresholds in the left and right ear are presented as threshold levels of each individual, the curve forms an artificial tip. When the average ear threshold is low, the thresholds of both ears have a tendency to be low and thus, there is a small difference between the ears. However, when the average ear threshold increases to its highest value, then the threshold levels of both ears become generally high. The difference between the ears begins to decrease after reaching the highest values, somewhere between the highest and the lowest values of the average threshold in the left and right ear.

Statistically significant difference was found between tone-hearing and speech detection thresholds among both groups of children. Both groups have better tone-hearing thresholds than speech detection thresholds. Among children with speech and language disorders, the difference is more pronounced and statistically significant at almost every tested frequency on both ears. Among children with normal speech and language development, it is interesting to notice that statistically significant difference in the mid-range and high frequency was detected in the right ear, and in the low frequencies in the left ear.

Comparison between the asymmetries that occur in tone-hearing thresholds and speech detection thresholds showed that there were no statistically significant differencesamong children with speech and language disorders. The difference among children with normal speech and language development was slightly more pronounced – the asymmetry was more pronounced in the tone-hearing thresholds than in the speech detection thresholds, at the frequency of 0,250, 4 and 8 kHz.

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# Examining the association between restricted, repetitive and stereotyped behavior and sensory response in minimally verbal children with ASD

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**Abstract.** Some theoretical frameworks, such as over- and under-arousal theory, have tried to offer an interpretation of restricted, repetitive and stereotyped behavior and its link to sensory dysfunction in children with ASD. There is limited examination of this link in subpopulations of children with ASD, such as those who are minimally verbal. This relation was examined on a clinical sample of children with ASD aged 3 to 6. Parents or caregivers answered the Sensory Profile 2. The participants were placed into categories according to their level of expressive language development. Results show that minimally verbal children with ASD have consistent difficulties in their sensory responses in everyday life, linked to greater severity of RRS symptoms. However, no unique sensory profile was found. This can be explained by the heterogeneity of this clinical group. The results are in accordance with earlier studies of RRS and sensory dysfunction in children with ASD. Systematic examination of subtypes within the spectrum is needed in order to create fully adequate treatment approaches for children with ASD.

## 1 Introduction

Recently, there is increased interest in sensory features in the population with autistic spectrum disorders (ASD in further text), as the new DSM – V draws more attention to the diagnostic category of restricted, repetitive and stereotyped behaviour (Donkers et al., 2015, Brock et al., 2012). This line of research has been neglected in the literature for some time, even though it can be found in the earliest descriptions of symptomatology of ASD. A number of empirical studies have shown sensory sensitivity in samples of children with ASD (Klintwall et al. 2010, Boyd et al. 2010,). Sensory processing (SP) refers to the way that sensory information is managed in the cerebral cortex and brainstem for the purpose of enabling adaptation to the environment and engagement in everyday activities (Johnson-Ecker & Parham 2000). Reviews of theories which are focused on sensory symptoms show that these issues have been examined as early as the sixties and seventies (Rogers and Ozonoff, 2005). Over-arousal theories claim that individuals with ASD are more likely to be overwhelmed with environmental stimuli and are slower or fail to habituate to them, when compared to the typical population.

One of the key questions, both in the clinical and research area is the connection between sensory features and repetitive and stereotyped behaviour. Restricted and repetitive behaviours form a class of behaviours characterized by high frequency, repetition in an invariant manner, and desire for sameness in the environment (Kanner, 1943). Most authors agree that one of the functions of this behaviour is inducing a sensory experience or reacting to sensory experience. However, there is sparse empirical evidence in this area so it is still too early to make certain assertions. There are complex reasons involved in this type of behavior – as some authors claim, with time, some behaviours become independent of the conditions that created them (Turner, 1999).

Research shows elevated results in sensory responsivity in clinical samples of children with ASD, compared to other groups, as well as wider dispersion of scores within possible score ranges (Ben-Sasson et al., 2008, Watling, Deitz & White, 2001, Baranek, David, Poe, Stone, & Watson, 2006; Rogers, Hepburn, & Wehner, 2003, Dunn, 2014).

Two studies examined the connection between sensory profiles and repetitive and stereotyped behaviour. In a study on school-aged children with ASD, Boyd and colleagues (2009) found a correlation of RBs and sensory features. Their sample consisted of high functioning individuals with ASD (IQ ≥70). Gabriels et al. (2008) also found significant co-occurrence between abnormal sensory responses and RBs in a subsample of children with ASD. This sample, however, had a wide age range: from 3 to 19 years, with relatively high IQ scores (average IQ of 81). Their sample also consisted of participants who used psychoactive medications and had co-morbid diagnoses. However, they showed a significant correlation between abnormal sensory response and RBs, regardless of IQ and psychotropic medication. There are also some older studies which have not found a connection between stereotypies with increase of experimentally induced sensory stimulation. The same was found in a situation of under-stimulation (Bernal & Miller, 1971; Frankel et al., 1976). However, these findings are methodologically quite different in comparison to previously described studies which used data received by parent questionnaires.

The aim of the current study was to examine parent-rated sensory profiles in a clinical group of young children with ASD and their association with restricted, repetitive and stereotyped behaviour and see if this relationship changed in connection with cognitive and language level of development. We also wanted to examine differences between sensory processing in children with different clinical diagnoses: ASD vs. specific language impairment (SLI in further text) in order to delineate the diagnostic distinction between ASD and SLI in the younger population of children.

## 2 Methodology

Two groups of participants were recruited for this study. The first group included children with ASD (N = 25) and children with specific language impairment (N = 21). Both groups were aged 3 through 6 (from 3 years 0 months to 6 years, 10 months). Inclusion criteria for the ASD group included a cut off of 55 as an autism index measure on the GARS scale (Gilliams, 2013). The study was carried out at the clinic of the Institute for Experimental Phonetics and Speech Pathology. The groups were matched according to chronological age. Exclusion criteria for both groups was the presence of comorbid conditions such as cerebral palsy, visual or hearing impairment, seizure disorders, prescription of pharmacological treatment or any type of syndrome. Most of the children in the sample have either started or were continuously included in speech therapy or occupational therapy (minimum of 3 months to maximum of 3 years). The ASD and SLI groups were matched group-wise, according to CA (chronological age).

### 2.1. Measures

#### 2.1.1. Diagnosis

The diagnosis of autistic spectrum disorder was established by a child psychiatrist using CARS and DSM–V (American Psychological Association, 2013). This documentation was part of the obligatory medical documentation within the patient’s dossier which is created upon submission at the IEPSP. The diagnosis of specific language impairment was established by an experienced speech and language therapist. The diagnosis was also confirmed by cognitive assessment resulting in a clinically indicative discrepancy between verbal and nonverbal cognitive abilities.

#### 2.1.2. Cognitive measure

Our ASD sample can be characterized as being at “the lower end of the spectrum”, most of the children were difficult to assess either due to lack of cooperation, or low language abilities. We adopted a protocol, based on research studies carried out on similar samples (Anderson et al., 2007, Norrelgen et al., 2015). A developmental hierarchy of cognitive tests was created. The child was given a psychological test according to his/her chronological age. If this test was too difficult, another test, lower in the hierarchy was used. The testing was complete when the child could achieve maximal results. The following tests for cognitive assessment, standardized on the Serbian sample, were used: The Brine-Lezine scale (1973), The Bine-Simone scale (1985) and REVISK (1997). The SLI sample was tested according to chronological age. All the participants showing a discrepancy between verbal and non-verbal abilities were placed in the SLI sample (elimination criteria, according to Stark & Tallal, 1981).