

Automatika

Journal for Control, Measurement, Electronics, Computing and Communications



ISSN: (Print) (Online) Journal homepage: <https://www.tandfonline.com/loi/taut20>

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To cite this article: Davor Šušković, Siniša Fajt & Vladimir Olujić (2021) Speech intelligibility in different types of audiograms and speech audiometry by using the simulated hearing loss on the speech material with normal hearing people, *Automatika*, 62:1, 118-126, DOI: 10.1080/00051144.2021.1887990

To link to this article: <https://doi.org/10.1080/00051144.2021.1887990>



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Published online: 16 Feb 2021.



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Speech intelligibility in different types of audiograms and speech audiometry by using the simulated hearing loss on the speech material with normal hearing people

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ABSTRACT

Presbycusis and noise-induced hearing loss result in characteristic audiogram curves with increasing levels of hearing loss at higher frequencies. Another specific form of audiogram curve is the cookie bite, which is often the result of inherited hearing loss and sometimes the result of illness or injury. The influence of the hearing loss on speech intelligibility was examined along with a list of words selected according to the frequency range of the phonemes present. Dependence of speech intelligibility and frequency of dominant hearing loss, at lower, middle and higher frequencies and over the whole range is shown. The method of speech audiometry with the simulated hearing loss on the speech material and the normal hearing people is presented.

ARTICLE HISTORY

Received 16 March 2020
Accepted 4 February 2021

KEYWORDS

Speech intelligibility; presbycusis; noise induced hearing loss; cookie bite; simulated hearing loss; speech audiometry

Introduction

Speech material used for the speech audiometry is the same for every type and degree of the hearing loss. In Croatia, the result of the speech audiometry gives an opportunity for the ENT (Otolaryngologists, commonly known as ear, nose and throat doctors or ENTs) to suggest binaural hearing where the cost of the both hearing instruments could be covered by health insurance [1]. The decision of the binaural prescription is often based on the result of the pure tone audiometry (PTA) [13]. The motivation for this study is to determine if the same degree of hearing loss – average PTA result on 500 Hz, 1, 2 and 4 kHz can result in different speech intelligibility depending on the shape of the audiogram.

Due to the various cognitive effects that could affect speech intelligibility in older people [2–4], the method of simulated hearing loss on the speech material is presented. Using the bandwidth filtering tools in the sound processing software, hearing loss is simulated on the recorded speech material for the normal hearing people [12]. The results are then compared with the ones from hearing impaired with the appropriate hearing loss.

Frequency range of the dominant hearing loss

The audiogram shows the hearing level threshold over the various frequencies [11]. Its graph is showing the

frequencies where bigger hearing loss is present, which depends on the type of hearing loss but also on specific characteristics of the individual, resonant frequencies of the ear canal and eardrum [5].

There are three recognizable audiograms that are common with hearing impaired people [6]:

- down-sloping with the fall of approximately 5–10 dB per octave which is common with people with presbycusis;
- substantially down-sloping after frequency of 1 kHz with dominant hearing loss around the 4 kHz which is common with people with the noise-induced hearing loss (NIHL) and
- “Cookie bite” shaped curve with dominant hearing loss at middle frequencies.

The speech signal is a very complex signal, considering its formation, processing and propagation. Viewed as an electrical signal, it represents its most complex type. The signal is non-stationary; it is variable in frequency and intensity and of a mainly transient nature with the sudden emergence and disappearance of certain speech phenomena. The signals are modulated in amplitude and frequency [7].

Hearing loss characterized by a decrease in hearing between the 500 Hz and 4 KHz, occurring in more than 90% of hearing impaired adults and 75% of children [8], prevents hearing of some components of the speech signal, leading to reduced intelligibility [9].

Spectrogram

Spectrogram is visually showing the sound's intensity and frequency as the function of time (x -axis) [10]. Higher intensity is showed as a darker grey (black) colour and frequency is on the y -axis. It is calculated by using the discrete Fourier transform (DFT) which transforms the sequence of numbers $f_0, f_1, f_2, \dots, f_{n-1}$ into sequence of numbers $F_1, F_2, F_3, \dots, F_{n-1}$.

$$F_j = \sum_{k=0}^{n-1} f_k \cdot e^{-\frac{2\pi i k j}{n}}$$

The spectrogram of the signal a in the window of time t is the matrix \hat{A} in which the columns are the DFT of the matrix A .

$$\hat{A} = \bar{F}A$$

$$A = \frac{1}{t}F\hat{A}$$

Each location in the matrix \hat{A} corresponds to a point in frequency and time. Therefore, the matrix \hat{A} as a spectrogram represents signal a .

The aim of this study is to examine the dependence of speech intelligibility on the frequency range of dominant hearing loss and compare the results of hearing impaired people with normal hearing people tested by the speech material with simulated hearing loss.

Goals and methods

Flowchart is shown in Figure 1.

Nine 2-syllable words were selected, divided into three groups by the representation of phonemes of predominantly higher, middle and lower frequencies. Selected words are "muklo", "umor", "bumbar" (LF – lower frequencies), "rana", "krava" and "dama" (MF – middle frequencies) and "stići", "splitski" and "lišće" (HF – high frequencies). It is precisely the represen-

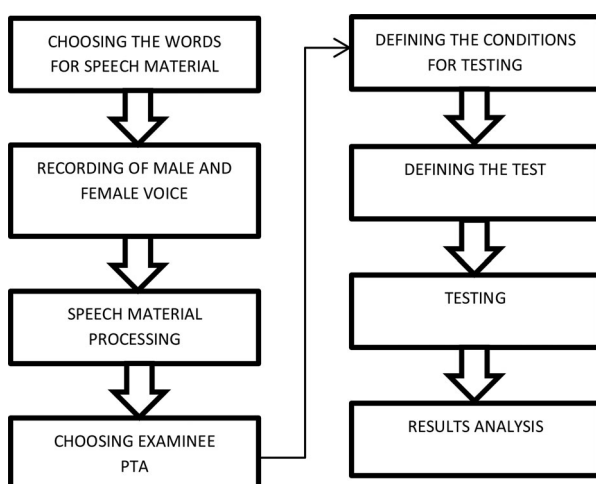


Figure 1. Flowchart.

tation of the phonemes of certain frequencies that is important to check the speech intelligibility of this test. Selected words are part of the speech material that is used in standard procedure of speech audiometry in all clinics in Croatia.

One male and one female speaker speak the words at standard speed. The recording was done in the sound-proof studio with suitable equipment. After recording, words were normalized by loudness.

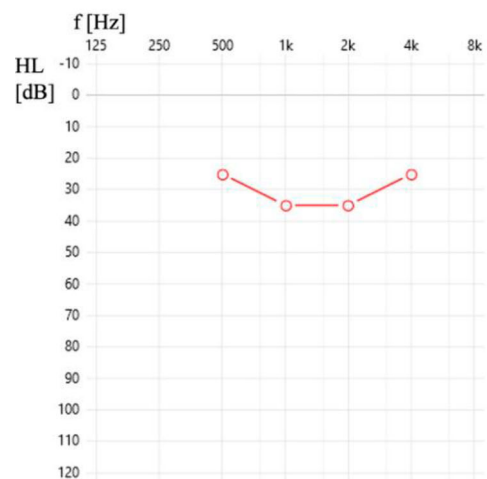
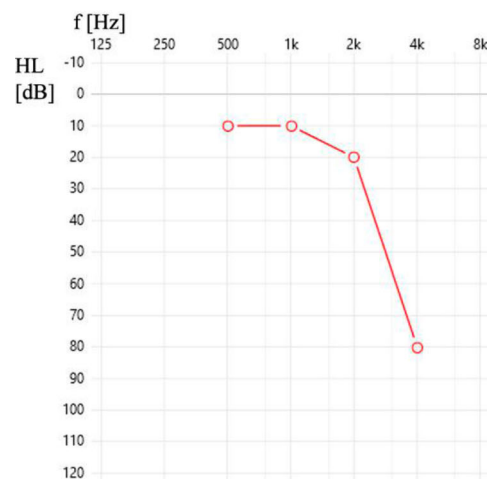
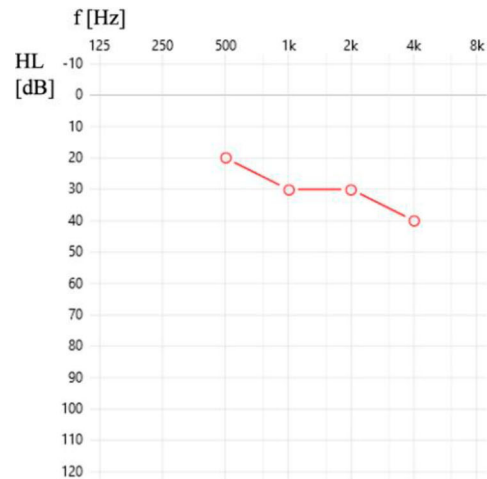


Figure 2. Audiograms; HL (Hearing Level) [dB] / f (frequency) [Hz].

Sound processing was done with Audacity v2.1.0 software. Three typical audiogram curves were selected with the average value of hearing loss of 30 dB at speech frequencies (500 Hz, 1 kHz, 2 kHz and 4 kHz) (Figure 2).

Each hearing loss was simulated at 0, -10 and -20 dB levels. A total of 162 words were recorded in random

order with a pause of 4 s between words. The total duration of the recorded speech material is 11 min and 3 s. The spectrograms of the selected words without simulated hearing loss and with the applied hearing loss are shown in the Figures 3–5. Spectrograms show the frequency range up to 7500 Hz.

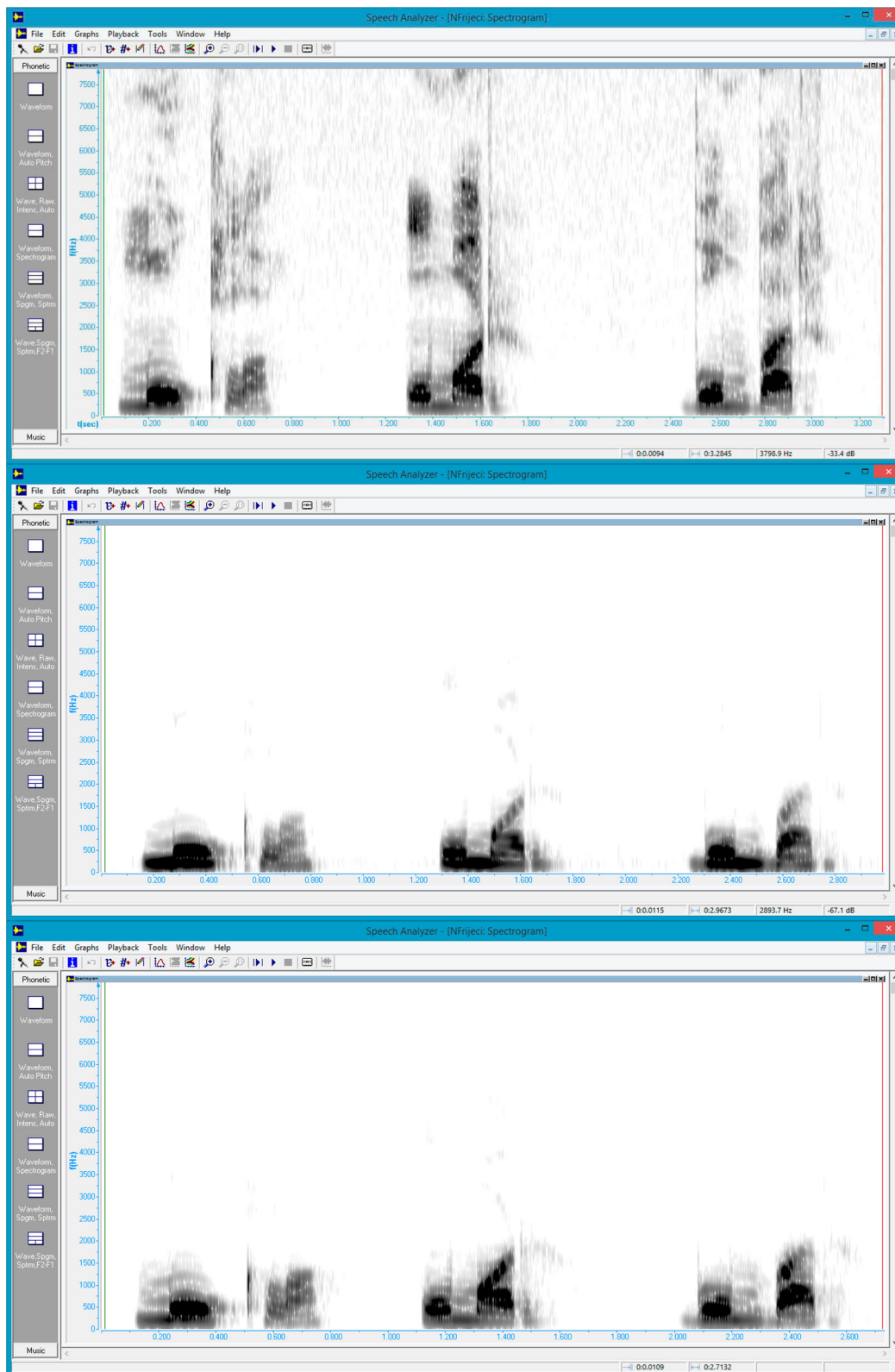


Figure 3. LF words in order: without HL (hearing loss), with simulated HL specific to presbycusis, NIHL and Cookie bite type.

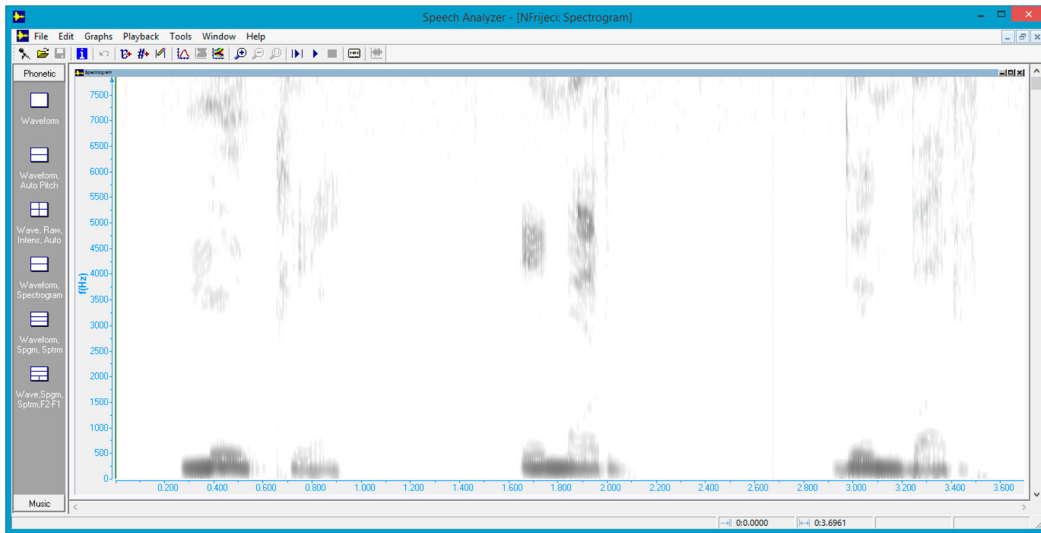


Figure 3. Continued.

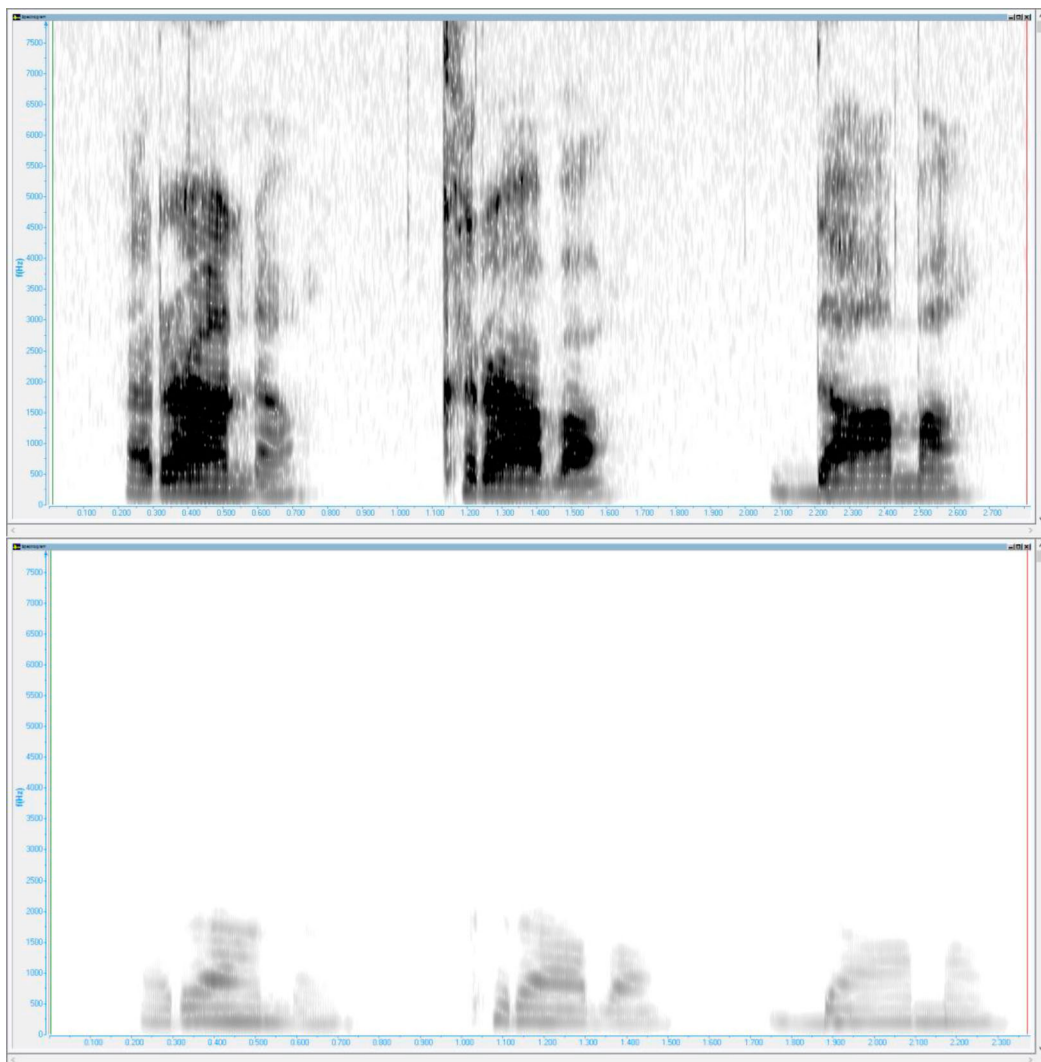


Figure 4. MF words in order: without HL, with simulated HL specific to presbycusis, NIHL and Cookie bite type.

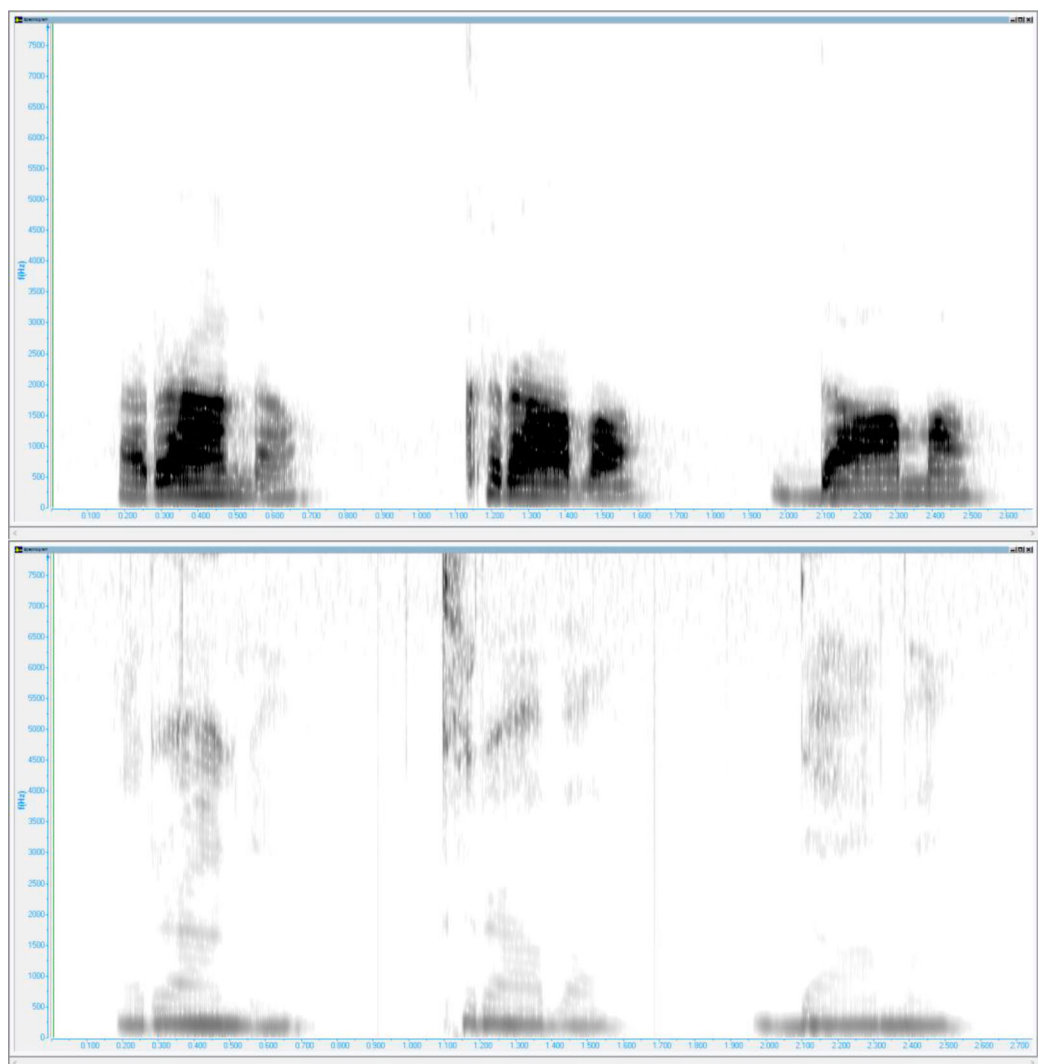


Figure 4. Continued.

Examinees were persons with normal hearing between the ages of 20 and 23 years. The average audiogram is shown in Figure 6. Examinees do not deviate more than 5 dB at an individual frequency from the average audiogram. Ten examinees were selected.

The testing is performed using a Grason-Stadler GSI Pello clinical audiometer with calibration performed. This audiometer is a versatile mid-level audiometer that can perform basic diagnostic audiometric evaluations but also has advanced tests such as TEN test, QuickSIN and high-frequency audiometry. The examinee is in an acoustically isolated room.

An examination form has been created in which the examinee types the words in order which they hear them (Figure 7). First cell is for entering the year of birth, second is for specifying the gender and the second row gives the instructions for entering the words in order. Words are entered in a 4-s pause between two words.

Speech audiometry procedure follows the recommendations from ISO:8253-3:2012 which specifies procedures and requirements for speech audiometry.

Speech material recording is played at 65 dBA, in a free field, with speakers at ear height 1 m away from the subject.

Result analysis

The results were analysed and grouped into appropriate groups. Only a completely correct word was judged as intelligible. Examination form for analysing the correctness of the entered words is shown in Figure 8. First letter shows the gender of the speaker (M – male, Ž – female), second letter shows the type of the hearing loss (P – Presbycusis, N – NIHL and C – Cookie Bite hearing loss), third symbol shows the sound level of the speech material (1 to –20 dB after applying the simulated hearing loss to the recorded material, 2 to –10 dB) and the fourth symbol is identifying the word as shown at the end of this examination form.

The results obtained are listed in the Table 1. Aud 1 stands for simulated presbycusis hearing loss, Aud 2 for simulated NIHL and Aud 3 for cookie bite hearing loss.

LF stands for words that mostly consists of low frequencies phonemes, MF stands for middle frequencies and HF for high frequencies. The result is shown in percentage by dividing the number of correct words and the total number of words.

Comparison of the results with those of the hearing impaired

Six people with appropriate hearing loss were selected with an average of hearing loss of 50 dB at speech frequencies (500 Hz, 1, 2 and 4 kHz), two for each

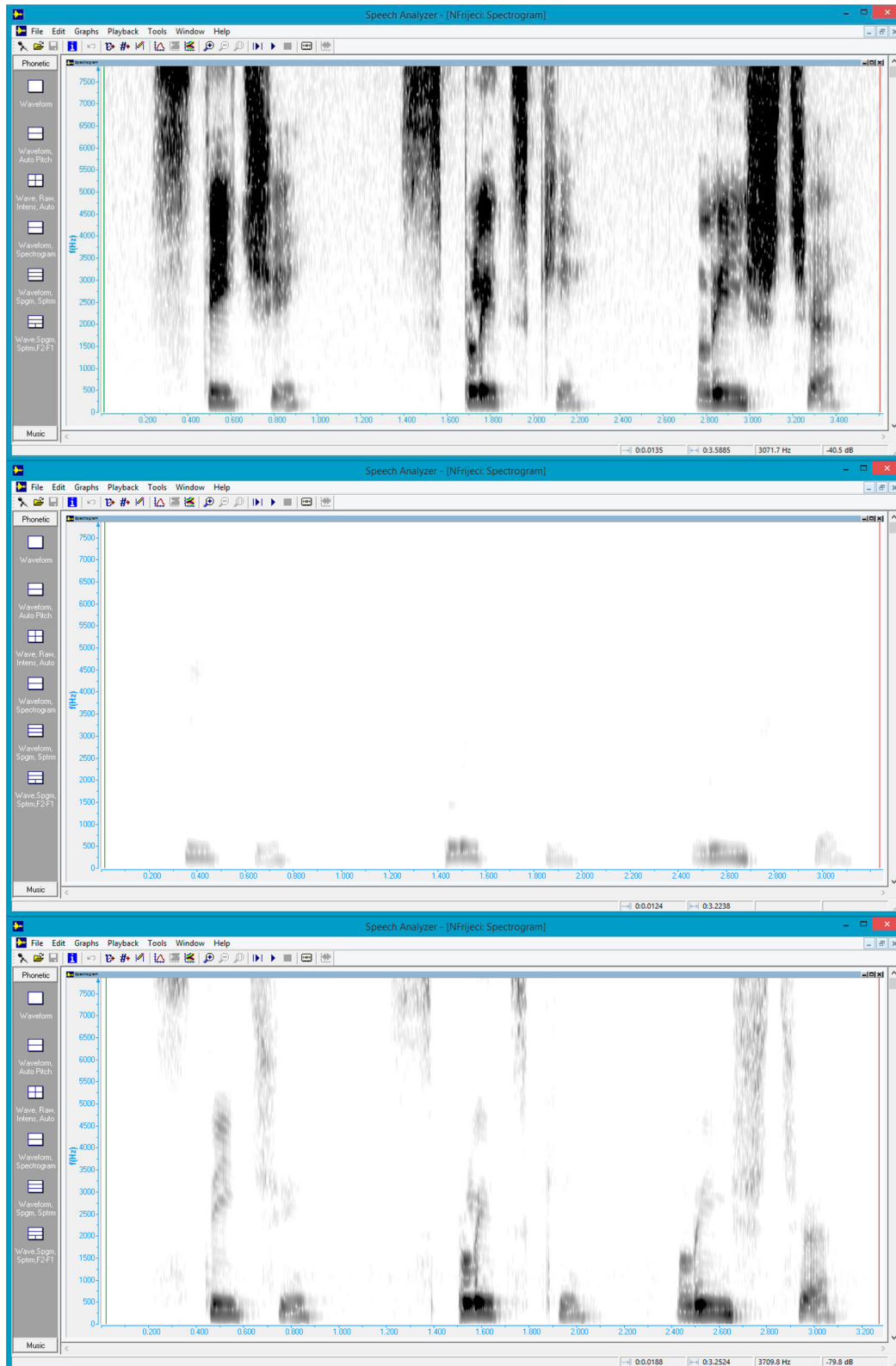


Figure 5. HF words in order: without HL, with simulated HL specific to presbycusis, NIHL and Cookie bite type.

GODINA ROĐENJA: 1991.			SPOL: M Ž		
Molimo riječi pišite redom, popunjavajući redove!					
Ž P 19	Ž N 19	Ž N 37	MP 18	Ž P 32	MC 29
MN 19	MC 13	MN 31	Ž C 18	MP 39	Ž N 18
MC 12	Ž C 17	MC 14	Ž C 15	MC 24	Ž C 22
MC 32	MP 25	Ž C 35	Ž P 37	Ž C 28	Ž C 27
MC 36	MP 15	MP 13	Ž P 27	Ž N 38	Ž C 16
MP 28	MN 28	Ž C 12	Ž P 13	MN 29	Ž N 39
MP 27	MN 22	Ž P 38	MC 16	MN 32	MP 12
Ž N 14	MP 29	Ž N 15	MN 24	MN 25	MN 12
MC 25	MP 19	Ž C 38	Ž P 29	Ž C 21	Ž N 33
MC 38	Ž C 36	MN 14	Ž N 36	Ž C 31	Ž P 31
MP 33	Ž P 39	Ž P 22	Ž N 24	Ž N 22	MP 24
MN 26	MN 34	Ž C 14	Ž N 27	MC 15	MC 17
MC 28	Ž N 16	MN 39	Ž C 19	Ž C 24	Ž P 15
Ž N 17	MC 31	Ž N 31	MN 15	MP 38	Ž C 25
MP 22	MN 33	MN 37	MC 21	MC 22	MP 17
MC 33	Ž P 36	MP 23	MC 37	MN 18	MP 21
MP 31	Ž C 33	MC 35	Ž N 25	MN 36	Ž P 24
Ž N 28	MN 21	Ž C 13	MP 37	Ž C 29	MP 34
Ž P 21	MC 26	Ž C 32	Ž P 11	MC 23	Ž P 17
MP 26	Ž P 16	Ž N 11	Ž P 12	Ž N 23	MN 17
MP 16	MN 13	MP 11	Ž C 26	MC 28	Ž N 26
Ž P 35	Ž P 26	Ž P 14	MP 14	MP 35	Ž N 12
MC 27	MN 16	MN 35	Ž P 33	Ž P 13	Ž C 11
MN 27	MN 38	Ž N 21	Ž P 18	Ž C 23	Ž C 34
MC 39	MN 23	Ž P 34	MC 11	Ž P 28	MP 36
Ž N 35	MP 32	MC 34	Ž C 37	Ž N 29	MC 19
Ž P 23	Ž C 39	Ž N 34	Ž N 32	Ž P 25	MN 11
1	MUKLO	4	RANA	7	STIĆI
2	UMOR	5	KRAVA	8	SPLITSKI
3	BUMBAR	6	DAMA	9	LIŠĆE

Figure 8. Examination form for analyzing the correctness of the entered words.

Table 1. Speech intelligibility results.

%	LF	MF	HF	Average
Aud 1	78.33	73.33	45.56	65.74
Aud 2	96.11	90.56	75.56	87.41
Aud 3	61.11	45.56	75.56	61.11

Table 2. Speech intelligibility results with hearing impaired.

%	LF	MF	HF	Average
Aud 1	79.63	64.81	50.00	64.81
Aud 2	100.00	90.74	59.26	83.33
Aud 3	64.81	55.56	64.81	61.73

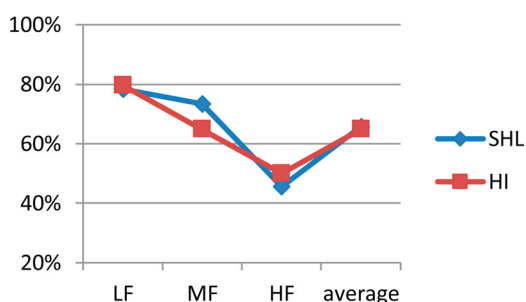


Figure 9. Comparison of the results of the simulated hearing loss (SHL) method and results for hearing impaired (HI) people with audiogram specific to people with presbycusis.

Conclusion

The study showed significant discrepancies in speech intelligibility as a function of the frequency range of dominant hearing loss. The largest discrepancy in

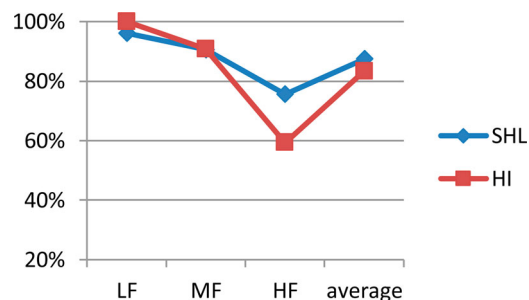


Figure 10. Comparison of the results of the simulated hearing loss (SHL) method and results for hearing impaired (HI) people with audiogram specific to people with NIHL.

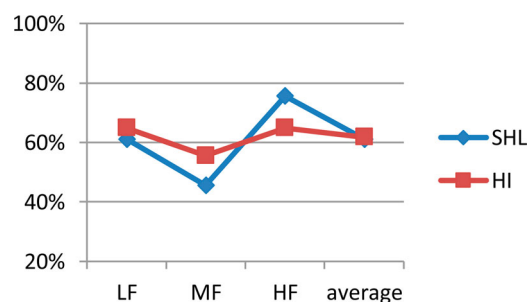


Figure 11. Comparison of the results of the simulated hearing loss (SHL) method and results for hearing impaired (HI) people with Cookie bite audiogram.

speech intelligibility is 45%, between the audiogram curve that is common for NIHL and the Cookie bite audiogram curve, for words that are represented by mostly mid-frequency phonemes.

The largest discrepancy in the speech intelligibility of words represented by phonemes of predominantly low frequencies is between the audiogram curve, which is common in NIHL, and the Cookie bite audiogram curve, and is 35%.

The largest discrepancy in the speech intelligibility of words represented by phonemes of predominantly high frequencies is between the audiogram curve common in presbycusis and the other two audiogram curves and is 30%.

The highest overall speech intelligibility of 87.41% was achieved with the NIHL, while the lowest speech intelligibility of 61.11% was achieved with the Cookie bite audiogram curve. Total speech intelligibility with the audiogram curve common to presbycusis is 65.74%.

The results obtained from hearing impaired people with appropriate hearing levels show similar results with a maximum absolute deviation of 4.08% and a relative of 4.67%.

Acknowledgements

(1) Providing information about current state in Croatia and world on the topic, Creating goals. Creating speech material. Testing the normal hearing subjects. Testing hearing impaired subjects. Analysing the results. Writing the manuscript. (2) Setting the test conditions. Setting the test

equipment. Analysing the results. (3) Creating speech material. Testing the normal hearing subjects. Analysing the results.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethical approval/patient consent

All tests and subjects are in accordance with the Helsinki Declaration as revised in 2013.

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