

THE ASSESSMENT OF INTELLIGIBILITY OF SPEECH IN THE AMBIENTAL CONDITIONS OF THE OFFICE

Dijana Kostić¹, Zoran Milivojević², Bojan Prlinčević³, Milan Cekić⁴, Violeta Stojanović⁵, Ratko Ivković⁶

¹Šargan inženjering Ltd Niš, Niš, Serbia;

² Engineering Academy of Serbia, Department of Electrical and Computer Engineering, Belgrade, Serbia;

³ Department of Information Technology Kosovo and Metohija Academy of Applied Studies, Leposavić, Serbia;

⁴ Mikkelsen Electronics Niš Niš, Serbia;

⁵ Department of Environmental Protection Academy of Applied Technical and Preschool Studies, Niš, Serbia;

⁶ Department of Software Engineering, Faculty of Economics and Engineering Management, University Business Academy in Novi Sad, Novi Sad, Serbia ;

* Corresponding author: koricanac@yahoo.com

Abstract

In this paper the assessment of speech intelligibility in the presence of different types of noise in a situation that happen in real life in ambient of office. In order to evaluate speech intelligibility in the presence of different kinds of noise, an experiment was conducted, using the binaural method. Matrix sentences obtained from words from the Serbian Matrix Sentence Test Base (SMST) were used as an input signal. The interference signals that were used: diffuse noise, and a combination of different types of noise that occur in the office environment (sound of a pen, keyboard, etc.) as well as early reflections. The parameters used for testing: SNR = (0, -2, -5) dB; b) speech signal angle $\phi_s = 0^\circ$; c) angle of reflection $\phi_n = 0^\circ$; e) angle of diffuse noise $\phi_{DN} = 0 : 5 : 360^\circ$; e) amplitude of reflection $A_r = 1$; f) delay time between direct and reflected signal $\Delta t = (0, 10, 25, 50)$ ms. The result of the test that is obtained is the STOI coefficient, for the left and for the right ear. After analyzing the results and comparing them with the results of similar tests and the IEC 60268-16:11 standard, a conclusion was brought about speech intelligibility.

Keywords: Intelligibility, SMST base, STOI, noise, binaural.

INTRODUCTION

In assessment of speech intelligibility in the presence of various noise: babble [1], industrial [2], rain [3] etc., different testing methods were used with appropriate types of speech materials for testing words [4] or sentences [5]. Many authors dealt with this topic using different methods approach. For testing speech intelligibility in the Serbian language authors was formed Serbian Matrix Sentence Test (SMST) base [6]. Test sentences are generated by random law of words from the SMST database, with respect specific form: name, verb, number, adjective, noun. In this paper the assessment of speech intelligibility in the presence of different types of noise in a situation that happen in real life in ambient of office. In order to assessment speech

intelligibility in the presence of different kinds of noise, an experiment, using the binaural method, was performed. As a results of testing the dSTOI coefficient [7] was obtained for left and right ear. Comparing results of testing with of similar tests and the IEC 60268-16:11 standard [8], a conclusion was brought about speech intelligibility.

The organization of work is as follows. Section II describes experiment, experimental results and analysis. Section III is conclusion.

EXPERIMENTAL RESULTS AND ANALYSIS

A. THE EXPERIMENT

In aim to estimate the intelligibility of speech in the presence of noise in the office

environment, the experiment shown in Fig. 1 was provided.

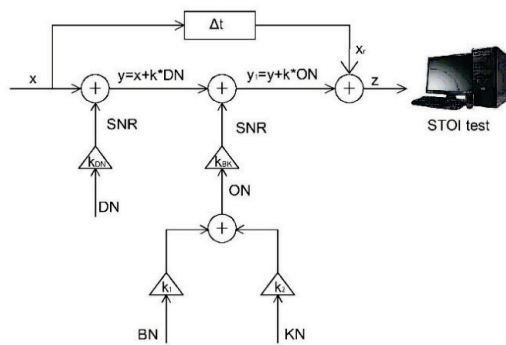
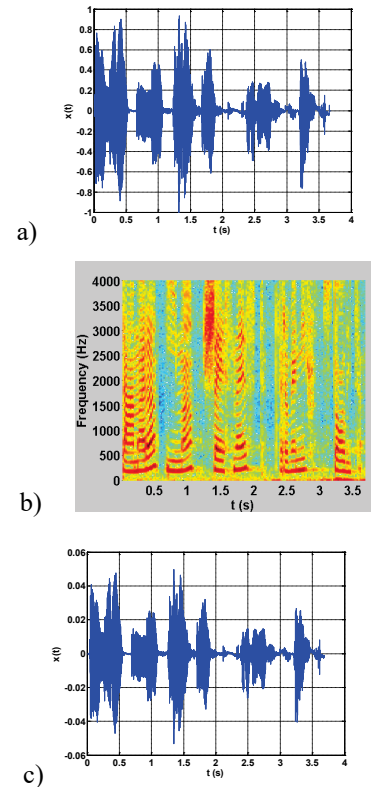


Fig. 1. Block diagram of the experiment

A test signal z was obtained by combining the reflected speech signal x_r with diffuse noise DN , and office ambient noise ON , with the desired signal-to-noise ratio (SNR) y_l . Matrix sentences composed of words from the SMST base were used as an input signal x . Diffuse noise is superimposed on signal x , as well as noise obtained by a combination of babble noise BN and noise caused by fast typing on the keyboard KN (to obtain the noise of an office environment, e.g. Office noise ON). The signal y is created by superimposing the speech signal x , and the diffuse noise DN , with the desired SNR, which is obtained by adjusting the coefficient k_{DN} . The signal y_l is created by superimposing the signal y and Office noise ON , with the desired SNR, which is obtained by adjusting the k_{BK} coefficient. Office noise ON is generated by superimposing Babble noise BN and Keyboard noise KN , adjusting coefficients $k_1 = (0, 0.5, 1)$ and k_2 , where $k_2 = 1 - k_1$. Babble noise and keyboard noise caused by fast typing on the keyboard are available on [9].

When coefficient have value: a) $k_1 = 0$, BN dominates, b) $k_1 = 0.5$ BN and KN signals have equal strength, and c) $k_1 = 1$, KN dominates. STOI coefficients were determined from the generated Test matrix sentences in Serbian: a) TS_1 : 'Tamara ima šesnaest crvenih stolica' (in English: 'Tamara has sixteen red chairs'), b) TS_2 : 'Marina pravi pet novih stolica' (in English:

'Marina makes five new chairs'), and c) TS_3 : 'Tomislav čisti petnaest različitih stolica' (in English: 'Tomislav clears fifteen different chairs'). The time and spectral characteristics of the Test signals (TS_1 , TS_2 and TS_3) are shown in Fig. 2 (TS_1), Fig. 3 (TS_2) and Fig. 4 (TS_3), for $SNR_{DN} = SNR_{ON} = -2$ dB: speech signal x , sentences obtained from the SMST base in Serbian language (a, b), reflected speech signal x_r (c, d) and, interference signal y_l , ON , (e, f), and test signal z (g, h). The parameters used in the realization of the binaural experiment, and on the basis of which the intelligibility testing is performed using the STOI test are: $SNR = (0, -2, -5)$ dB; b) excitation angle of speech signal $\phi_s = 0^\circ$, c) angle of reflection $\phi_n = 0^\circ$; e) angle of diffuse noise $\phi_{DN} = 0 : 5 : 360^\circ$, e) amplitude of reflection $Ar = 1$, f) delay time between direct and reflected signal $\Delta t = (0, 10, 25, 50)$ ms. Testing was done for cases, when: a) $SNR_{DN} = SNR_{ON}$ and b) $SNR_{DN} \neq SNR_{ON}$. The result of the of the experiment, are the coefficients STOI, which were obtained using the STOI algorithm, for the left (dSTOI_L) and for the right (dSTOI_R) ear.



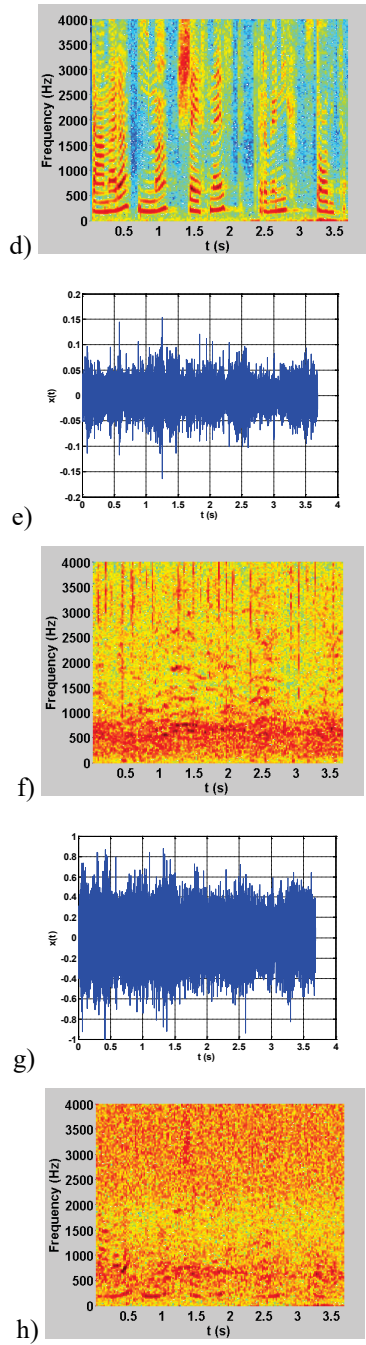


Fig. 2. Time and spectral characteristic TS_1 , for $k_1=0.5$, $\Delta t=25\text{ms}$: TS_1 (a, b). Time of delay TS_1 25 ms (c, d). Office noise (e, f). TS_1 with superimposed noises (g, h).

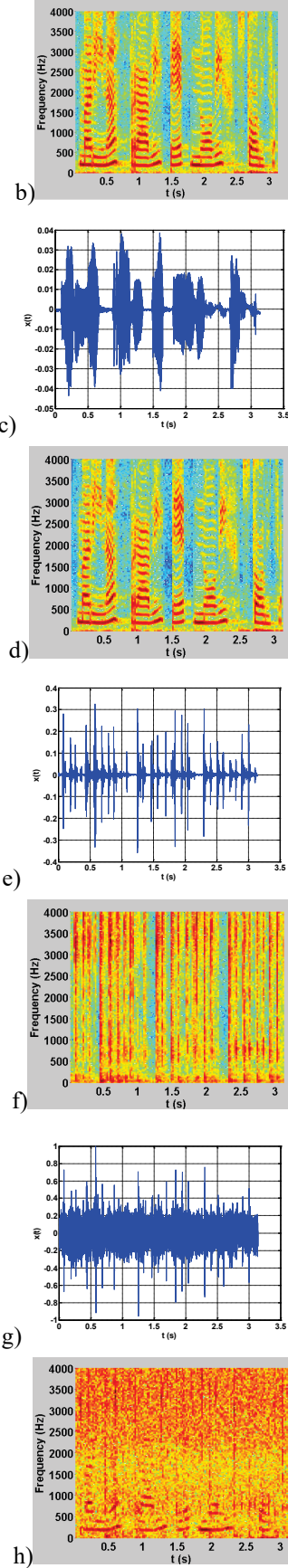
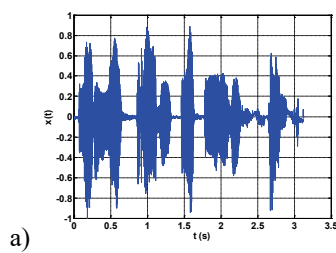


Fig. 3. Time and spectral characteristic TS_2 , for $k_1=0$, $\Delta t=25\text{ms}$: TS_2 (a, b). Time of delay TS_2 25 ms (c, d). Office noise (e, f). TS_2 with superimposed noises (g, h).

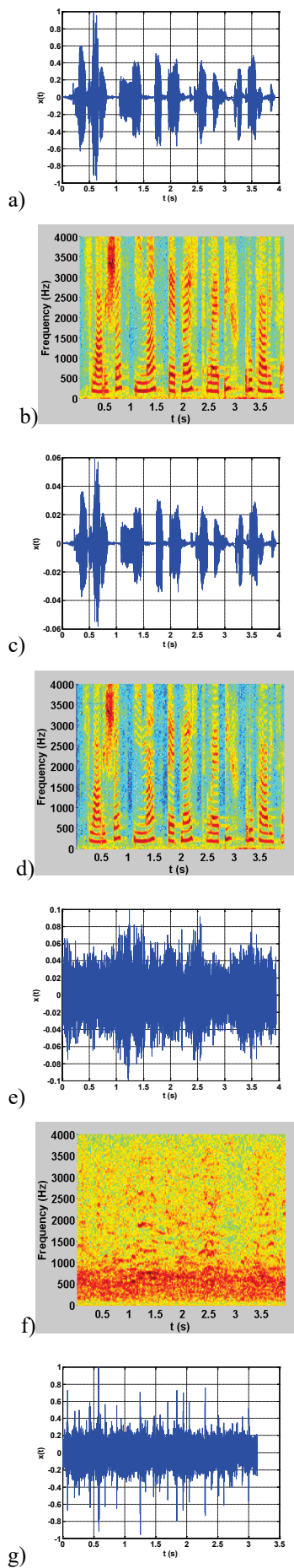


Fig. 4. Time and spectral characteristic TS_3 for $k_I = 1$, $\Delta t = 25$ ms: Test sentence TS_3 (a, b). Time of delay TS_3 25 ms (c, d). Office noise (e, f). TS_3 with superimposed noises (g, h).

B. THE RESULTS

The test results (intelligibility coefficients dSTOI) are presented in tabular form, for $SNR_{DN} = SNR_{ON}$, and values of the coefficient k_I : a) $k_I = 0$ (Tbl. 1), b) $k_I = 0.5$ (Tbl. 2), and c) $k_I = 1$ (Tbl. 3). The intelligibility coefficients dSTOI, are presented in tabular form, for $SNR_{DN} \neq SNR_{ON}$, and values of the coefficient k_I : a) $k_I = 0$ (Tbl. 4), b) $k_I = 0.5$ (Tbl. 5), and c) $k_I = 1$ (Tbl. 6).

TABLE I. INTELLIGIBILITY $k_I = 0$, $SNR_{DN} = SNR_{ON}$

SNR (dB)	dSTOI	Intelligibility				
		Δt (ms)				μ
		0	10	25	50	
0	dSTOIL	0.5687	0.5577	0.5401	0.6854	0.5880
	dSTOIR	0.5734	0.5706	0.5538	0.6880	0.5964
-2	dSTOIL	0.4486	0.5508	0.5931	0.6759	0.5671
	dSTOIR	0.4599	0.5414	0.6011	0.6845	0.5717
-5	dSTOIL	0.6133	0.5370	0.5408	0.5392	0.5576
	dSTOIR	0.6268	0.5465	0.5362	0.5240	0.5584

TABLE II. INTELLIGIBILITY $k_I = 0.5$, $SNR_{DN} = SNR_{ON}$

SNR (dB)	dSTOI	Intelligibility				
		Δt (ms)				μ
		0	10	25	50	
0	dSTOIL	0.6995	0.5751	0.5704	0.5801	0.6063
	dSTOIR	0.6971	0.5721	0.5773	0.5725	0.6048
-2	dSTOIL	0.6365	0.5634	0.5188	0.5190	0.5594
	dSTOIR	0.6294	0.5672	0.5037	0.5263	0.5567
-5	dSTOIL	0.5809	0.4924	0.4810	0.4530	0.4999
	dSTOIR	0.5825	0.4916	0.4748	0.4359	0.4962

TABLE III. INTELLIGIBILITY $k_I = 1$, $SNR_{DN} = SNR_{ON}$

SNR (dB)	dSTOI	Intelligibility				
		Δt (ms)				μ
		0	10	25	50	
0	dSTOI _L	0.7118	0.5138	0.5777	0.5430	0.5866
	dSTOI _R	0.7083	0.5190	0.6005	0.5433	0.5978
-2	dSTOI _L	0.6472	0.5744	0.6106	0.5177	0.5875
	dSTOI _R	0.6359	0.5708	0.6130	0.5279	0.5869
-5	dSTOI _L	0.5675	0.4658	0.5321	0.4638	0.5073
	dSTOI _R	0.5715	0.4708	0.5201	0.4776	0.5100

TABLE IV. INTELLIGIBILITY $k_I = 0$, $SNR_{DN} \neq SNR_{ON}$

SNR (dB)	dSTOI	Intelligibility				
		Δt (ms)				μ
		0	10	25	50	
-2	dSTOI _L	0.7093	0.5615	0.5845	0.5090	0.5911
	dSTOI _R	0.7220	0.5700	0.5875	0.5167	0.5990
-5	dSTOI _L	0.5900	0.5474	0.5600	0.4644	0.5404
	dSTOI _R	0.5920	0.5507	0.5695	0.4669	0.5448

TABLE V. INTELLIGIBILITY $k_I = 0.5$, $SNR_{DN} \neq SNR_{ON}$

SNR (dB)	dSTOI	Intelligibility				
		Δt (ms)				μ
		0	10	25	50	
-2	dSTOI _L	0.6365	0.5940	0.5354	0.4968	0.5657
	dSTOI _R	0.6340	0.5932	0.5416	0.4980	0.5667
-5	dSTOI _L	0.6252	0.5351	0.5059	0.4520	0.5295
	dSTOI _R	0.6218	0.5291	0.5055	0.4587	0.5288

TABLE VI. INTELLIGIBILITY $k_I = 1$, $SNR_{DN} \neq SNR_{ON}$

SNR (dB)	dSTOI	Intelligibility				
		Δt (ms)				μ
		0	10	25	50	
-2	dSTOI _L	0.6874	0.5105	0.5075	0.5714	0.5692
	dSTOI _R	0.6848	0.5163	0.5003	0.5719	0.5683
-5	dSTOI _L	0.6467	0.4658	0.5321	0.4638	0.5271
	dSTOI _R	0.6424	0.4708	0.5201	0.4776	0.5277

C. THE ANALYSIS

Analyzing the results the coefficients STOI, which were obtained using the STOI algorithm, for the left (dSTOI_L) and for the right (dSTOI_R) ear (Tbl. 1 – Tbl. 6), it was observed that the coefficients intelligibility dSTOI_L and dSTOI_R goes from: a) 0.4486 - 0.6880 for $k_I=0$, $SNR_{DN} = SNR_{ON}$ and 0.4644 - 0.7220 for $SNR_{DN} \neq SNR_{ON}$, b) 0.4530 - 0.6995 for $k_I = 0.5$, $SNR_{DN} = SNR_{ON}$ and 0.4520 - 0.6365 for $SNR_{DN} \neq$

SNR_{ON} , and c) 0.4638 - 0.7118 for $k_I = 1$, $SNR_{DN} = SNR_{ON}$ and 0.4638 - 0.6874 for $SNR_{DN} \neq SNR_{ON}$. The best intelligibility were obtained for $SNR_{DN} = SNR_{ON} = -2$ dB is dSTOI_R = 0.7220 and dSTOI_L = 0.7093. It can also be observed that, in general, the intelligibility at $SNR = -2$ dB is better than for the other cases ($SNR = 0$ and $SNR = -5$). Also, by increasing the time of delay to $\Delta t = 25$ ms, or 50ms, an improvement in speech intelligibility is observed. By comparing the results obtained for the left and right ear, results are generally better for right ear, which proves theory of research Audiology researchers at Auburn University in Alabama [10].

Analysing of many study which tested influence of noise in office environments showed a negative effect on employees. Some of them have influence on health, other on productivity. As a primary source of noise annoyance for other employees show that the conversation between individuals and their colleagues (Babble noise) [11]. Besides on intelligibility of speech, the noise have a negative effect on employees ability to focus to performing their tasks [12], and also increased frustration and stress among employees [12]. A study performed by Oseland stated that 92% of employees reported that noise made their job performance less productive [13].

CONCLUSION

The paper presents the results of the experiment, which relate to intelligibility in conditions of diffuse noise DN , office noise ON , which consists of babble BN and keyboard noise KN , as well as reflection. Intelligibility is represented by the intelligibility coefficient, which was determined using the STOI algorithm, for the left (dSTOI_L) and right (dSTOI_R) ear. By comparing the results coefficients intelligibility, obtained experimentally for different value of SNR, and analyzing the time and spectral characteristics of the signals, it is observed, that the babble noise

BN intensively affects the degradation of intelligibility. This stems from the fact that *BN*, which is a consequence of the speech of a large number of people, has an energy distribution in the spectrum that is equivalent to the energy distribution of a speech signal. In this way, time and spectral masking of the speech signal is intensively performed, so that *BN*, in relation to *DN*, reflections and *KN*, has a dominant degradation of intelligibility. By comparative analysis of the experimental coefficients of intelligibility (range 0.4486 to 0.7220) with classification coefficients of intelligibility defined by standard IEC 60268-16, it is concluded that speech intelligibility in the ambient conditions of Office, with the parameters tested ($SNR = (0, -2, -5)$ dB, signal $\phi_s = 0$, $\phi_n = 0^\circ$, $\phi_{DN} = 0 : 5 : 360^\circ$, $Ar = 1$, $\Delta t = (0, 10, 25, 50)$ ms, $k_l = (0, 0.5, 1)$), is poor.

REFERENCE

- [1] Kostić D, Milivojević Z, Veličković Z, The influence of early reflections and Babble noise on the intelligibility of speech signal, ICEST 2019, Ohrid, Macedonia, pp.150-153, 2019
- [2] Milivojević Z, Kostić D, Brodić D, The Influence of Industrial Noise on the Performance of Speech Intelligibility Serbian Sentence Matrix Test, ICEST Niš, pp. 301-304, 2017.
- [3] Kostić D, Milivojević Z, Veličković Z, Influence of the rain noise to intelligibility in Serbian language, UNITEH 2018, Gabrovo, pp. 252-257, 2018.
- [4] Clark J.E, Four PB word lists for Australian English, Aust. J. Audiology 3(1), 21-31, 1981.
- [5] Plomp R, Mimpen A.M, Improving the reliability of testing the speech reception threshold for sentences, Audiology, 18, 43–52, 1979.
- [6] Milivojević Z, Kostić D, Veličković Z, Brodić D, Serbian sentence matrix test for speech intelligibility measurement in different reverberation conditions, UNITEH Gabrovo, 2016.
- [7] Milivojević Z, Kostić D, Veličković Z, The Optimization of the STOI Algorithm Parameters in Presence of the White Gaussian Noise (WGN), ICEST 2018, 2018.
- [8] International Electrotechnical Commission IEC 60268-16 - International Standard: Sound system equipment – Part 16: Objective rating of speech intelligibility by speech transmission index, Switzerland: IEC, 2011.
- [9] <https://mixkit.co/free-sound-effects/>
- [10] Acoustical Society of America. “Want to listen better? Lend a right ear.ScienceDaily. Retrieved August 30, 2021 from www.sciencedaily.com/releases/2017/12/171206090611.htm
- [11] Di Blasio S, Shtrepi L, Puglisi G.E, Astolfi A, A Cross-Sectional Survey on the Impact of Irrelevant Speech Noise on Annoyance, Mental Health and Well-being, Performance and Occupants’ Behavior in Shared and Open-Plan Offices. Int J Environ Res 2019; 16(2):280
- [12] Seddigh A, Berntson E, Danielson C.B, Westerlund H, Concentration requirements modify the effect of office type on indicators of health and performance, J Environ Psychol; 38:167-74, 2014.
- [13] Oseland N, Hodsman P, A psychoacoustical approach to resolving office noise distraction, J Corp Real Estate; 20(4):260-280, 2018.