Characteristics of Voice in Individuals with Multiple Sclerosis

Mirela Duranovic[1], Nevzeta Salihovic[1], Amela Ibrahimagic[1], Nermin Toromanovic[2]
Faculty of Education and Rehabilitation, University of Tuzla, Tuzla, Bosnia and Herzegovina[1]
Health center Cazin, Bosnia and Herzegovina[2]

PROFESSIONAL PAPER

SUMMARY

Background: Individuals who suffer from multiple sclerosis, aside from other symptoms, usually have voice changes such as poor control of pitch, variations in voice intensity, altered voice quality and resonance disorders. **Purpose:** The purpose of this study was to determine voice acoustic characteristics in individuals with multiple sclerosis and to compare those results with control group. **Methods**: This study was conducted on 17 subjects, both males and females, of chronological age between 27 and 55 years. All subjects were diagnosed with multiple sclerosis by professional neurologist. Control group consisted of 17 subjects who matched with experimental group of the same age and sex. The study was conducted at the Clinic for Neurology, University Clinical Centre Tuzla. Sustained phonation of vowel /A/ was analyzed by computer programme for voice analysis MDVP (Multi Dimensional Voice Program). **Results**: Results of our study exhibited statistically significant differences between subjects with multiple sclerosis and control subjects in variables standard deviation of fundamental frequency and phonatory F0 range. We also found statistically significant differences between variable related to pitch perturbation (jitter) and peak-to-peak amplitude variation. Statistically significant differences were also determined between subjects with multiple sclerosis and control subjects in variables related to degree of irregular vocalization, noise to harmonic ratio and variable related to amplitude tremor intensity index. **Conclusion**: Results of this study showed that subjects with multiple sclerosis exhibited significant variation in voice acoustic characteristics compared to control group. MDVP can be a useful tool for further monitoring of voice characteristics alterations in patients with multiple sclerosis during diagnostic and treatment processes.

Key words: voice, multiple sclerosis, acoustic analysis.

1. INTRODUCTION

Patients with multiple sclerosis often have motor, sensitive or cognitive impairments that interfere with their communication abilities and their swallowing (1). Speech disorders in patients with multiple sclerosis can be sometimes disabling (2), and they can also manifest themselves through motor speech aspects (dysarthria), respiratory deficits, voice disorders (dysphonia), and high level of problems in language and cognitive functions such as comprehension and expression (1). Severity of speech deviation in individuals with multiple sclerosis was positively correlated to severity of neurological deficit, type of disease course and number of years in progression (3).

Several researchers made a list of speech symptoms: 1) impaired loudness control, 2) voice harshness; 3) disordered articulation; 4) impaired emphasis; and 5) impaired pitch control.

Dysarthria occurs in approximately 40% of all patients with multiple sclerosis (5). Multiple sclerosis can affect myelin just about anywhere within the CNS. When there is bilateral involvement of the upper motor neurons, spastic dysarthria may be one of the consequences of multiple sclerosis (MS). MS also may result in other types of dysarthria, such as ataxic or mixed dysarthria (6). Dysarthrias of multiple sclerosis are best categorized as spastic-ataxic dysarthria with disturbances of voice intensity, voice quality, articulation and intonation (3, 4, 7). If we look at the problem only from the aspect of voice, it is necessary to point out changes in pitch, variations in voice loudness, alterations in voice quality and resonance disorders (8). Although patient with dysarthria can exhibit difficulties in articulation and prosody, parameters related to voice (phonation and resonance) can result in major problems and symptoms (9). Dysphonia can be present as one component of dysarthria including problems with vocal cords, and therefore with voice production (4). Vocal cords can vibrate in an unsynchronized manner, resulting in a spastic movement which makes speech comprehension difficult (10). The main purpose of this study was to determine voice acoustic characteristics in individuals with multiple sclerosis and to compare those results with voice acoustic characteristics of control group.

2. SUBJECTS AND METHODS

This study was conducted on 17 subjects (5 males and 12 females) of chronological age between 27 and 55 years. All subjects were diagnosed with multiple sclerosis by professional neurologist. Control group consisted of 17 subjects who matched with experimental group of the same age and sex. The study was conducted at the Clinic for Neurology,

University Clinical Centre Tuzla. All subjects had undergone neurological assessment with confirmed diagnosis of multiple sclerosis.

The sample of variables consisted of following variables: AGE: age of subjects–expressed in years; G1 – subjects of control group; G2–subjects with multiple sclerosis; ACOUSTIC VARIABLES: F0 – average fundamental frequency; MF0 – fundamental frequency of male subjects; FF0 – fundamental frequency of female subjects; XF0 – fundamental frequency for both male and female subjects; STD–standard deviation of fundamental frequency; PFR – phonatory F0 range in semitones; FFTR–frequency tremor intensity index in Hz; FATR–amplitude tremor frequency; Jitter–jitter in percentage (fundamental frequency variation – in %); vF0 – coefficient of variation of the fundamental frequency; ShdB – shimmer in decibels (perturbation of amplitude in the vocal tone in dB); vAm–peak-to-peak amplitude coefficient of variation–in %; DUV–degree of irregular vocalization; NHR – noise to harmonic ratio; VTI – voice turbulence index; SPI – soft phonation index; ATRI–amplitude tremor intensity index – in %; NVB – number of voice breaks. Computer program for voice analysis Multi Dimensional Voice Program (MDVP) (Kay Elemetrics Corp., Pine Brook, NJ) was used for acoustic analysis of sustained phonation of vowel /A/, and by this analysis variables for determining of voice acoustic characteristics were obtained. The MDVP is a computer program that can calculate as many as 33 acoustic parameters from a voice sample. The MDVP appears to have potential for rapid quantitative assessments of voice in both research and clinical applications (11).

	Control group (N=17)		Multiple sclerosis (N=17)	
Variable	X	SD	X	SD
AGE	40,94	6,39	41,06	6,36
MF0-male	113,43	28,13	152,80	46,14
FF0-female	200,71	27,21	165,45	45,64
STD	5,02	4,93	17,03	23,67
PFR	6,58	2,96	12,65	9,07
FFTR	3,97	1,66	4,81	2,36
FATR	3,69	1,21	4,50	2,72
JITTER	0,98	0,37	2,40	2,03
VF0	2,89	2,27	9,39	11,23
SHIMMER	0,64	1,31	0,79	0,84
VAM	24,66	12,11	36,66	17,46
DUV	1,68	2,33	8,91	15,69
NHR	0,14	0,02	0,20	0,12
VTI	0,04	0,01	0,04	0,01
SPI	17,70	7,48	21,87	7,00
ATRI	4,68	2,40	12,58	9,22
NVB	0,13	0,34	3,24	8,30

Table 1. Basic statistic parameters of voice acoustic variables

Upon determining that subject had multiple sclerosis, an audio recording of subject's three consecutive vowel /a/ phonations was made for the purpose of phonation parameters evaluation. The microphone (an electret condenser microphone Sony ECM-MS907) was placed 30 cm in front of the subject's mouth, and voices were recorded using high quality a Sony Portable Mini-Disc Player/Recorder (MZ-R91). The same procedure was conducted in control group. Data on voice parameters were obtained by software analysis. Quantitative acoustic-statistical voice analysis of analyzed groups was performed by the MDVP. Basic statistic parameters were calculated for each variable applied in this study. T-test was used for examination of differences between subjects who suffer from multiple sclerosis and control group. Correlation analysis was used for determining possible correlation between analyzed variables.

	G1 (N = 17)		G2 (N = 17)					
Variable	X1	STD1	X2	STD2	t test	df	P	P variance
XF0	175,250	48,617	164,000	44,438	0,76	39	0,454	0,951
STD	5,015	4,930	17,031	23,666	-,43	39	0,020	0,000
PFR	6,583	2,962	12,647	9,069	-3,07	30	0,004	0,000
FFTR	3,972	1,659	4,805	2,357	-1,28	36	0,208	0,047
FATR	3,690	1,208	4,500	2,723	-1,15	29	0,259	0,002
JITTER	0,982	0,373	2,402	2,026	-3,37	39	0,002	0,000
vF0	2,894	2,270	9,394	11,226	-2,77	39	0,009	0,000
SHIMMER	0,644	1,314	0,786	0,837	-0,39	39	0,697	0,988
vAM	24,658	12,110	36,659	17,461	-2,60	39	0,013	0,012
DUV	1,677	2,327	8,907	15,688	-2,23	39	0,031	0,005
NHR	0,140	0,023	0,198	0,115	-2,41	39	0,021	0,001
VTI	0,042	0,013	0,038	0,011	1,09	39	0,281	0,854
SPI	17,697	7,480	21,871	7,004	-1,81	30	0,079	0,621
ATRI	4,683	2,404	12,583	9,222	-3,66	29	0,001	0,000
NVB	0,125	0,338	3,235	8,296	-1,84	39	0,073	0,003

G1: subjects from control group; G2: subjects with multiple sclerosis, X1: mean values of variables for subjects from control group, X2: mean values of variables for subjects with multiple sclerosis

Table 2. Differences in mean values of voice acoustic variables between subjects from control group and subjects with multiple sclerosis

3. RESULTS

Results of the study related to acoustic parameters of sustained phonation of vowel /A/ in subjects with multiple sclerosis and control group were obtained by acoustic analysis of recorded voices with computer program for voice analysis MDVP. Basic statistic parameters of analyzed variables are displayed in Table 1. Analysis of results displayed in Table 1 indicate that mean age in subjects from control group was 40,94 years, and in subjects with multiple sclerosis 41,06 years. Mean value of variable fundamental frequency in male subjects from control

group (MF0) was 113,43 Hz, and for female subjects it was 200,71 Hz, which is in accordance with mean fundamental frequency characteristic for males and females in general. We obtained higher values of fundamental frequency for male subjects with multiple sclerosis (MF0 – 152,80 Hz), whereas for female subjects with multiple sclerosis we obtained lower values of fundamental frequency (FF0 – 165,45 Hz) compared to mean value of F0 from control group. Mean value for standard deviation of fundamental frequency was higher in subjects with multiple sclerosis (17,03), whereas in subjects from control group this value was significantly lower (5,02). Mean value of phonatory F0 range in semitones (PFR) was also higher in subjects with multiple sclerosis, and it was 12,65, whereas for subjects from control group it was 6,58. Frequency tremor intensity index in Hz (FFTR) was higher in subjects with multiple sclerosis, and lower in subjects from control group. Additionally, values for amplitude tremor frequency (FATR) were higher in subjects with multiple sclerosis, and lower in subjects from control group.

Mean value of jitter, variable related to pitch perturbation, in subjects with multiple sclerosis was 2,40%, and in subjects from control group it was 0,98%. Mean value of coefficient of variation of the fundamental frequency (vF0) was higher in subjects with multiple sclerosis (9,39%), and lower in subjects from control group (2,98%). Mean value of short-term perturbation of amplitude in the vocal tone (in dB–Shimmer) was higher in subjects with multiple sclerosis (0,79dB), whereas in subjects from control group those value was 0,64 dB. Perturbation in amplitude of vocal tone was confirmed through values of variable related to peak-to-peak amplitude variation (vAm) in subjects with multiple sclerosis – mean value was 36,66%, and in control group mean value was 24,66%. We obtained higher degree of irregular vocalization (DUV) in subjects with multiple sclerosis (8,91%), and it was significantly lower in subjects from control group (1,68%). Mean value of amplitude tremor intensity index was higher in subjects with multiple sclerosis (12,58%), and was significantly lower in subjects from control group (4,68%). Subjects with multiple sclerosis had greater number of voice breaks (3,24), and subjects from control group had only 0,13 breaks during phonation. Possible statistically significant differences between two groups of subjects will be determined by other statistical analyses.

T-test was used to determine differences between subjects with multiple sclerosis and subjects from control group in variables determining voice acoustic characteristics. Results of this study showed statistically significant differences between subjects with multiple sclerosis and subjects from control group in variables standard deviation of fundamental frequency (STD: $p<0,020$) and phonatory F0 range (PFR: $p< 0,004$). We also determined statistically significant differences between variable related to fundamental frequency variation (JITTER: $p<0,002$ and vF0: $p<0,009$), and variable related to variation in peak-to-peak amplitude (vAM: $p<0,013$). Additionally, we determined statistically significant differences between subjects with multiple sclerosis and subjects from control group in variables related to degree of irregular vocalization (DUV: $p<0,031$), variable related to noise to harmonic ratio (NHR: $p<0,021$) and variable related to amplitude tremor intensity index (ATRI: $p<0,001$).

4. DISCUSSION

Fundamental frequency perturbation is sufficiently sensitive to pathological changes in the phonatory process and to severe respiratory insufficiency (12) what justifies complete utility of measurement of frequency perturbation in evaluation of voice and laryngeal pathology. Perturbation analysis of sustained vowel waveforms is used routinely in the clinical evaluation of pathological voices and in monitoring patient progress during treatment (13). Results of pathological voice production provide data on values of fundamental frequency, phonatory frequency range, several frequency and amplitude short- and long-term perturbation and variation measures, noise-to-harmonic ratio, quantitative measures of voice breaks, sub-harmonic components and vocal tremors (14).

Results of the study related to acoustic parameters of sustained phonation of vowel /A/ in subjects with multiple sclerosis and subject from control group were obtained by acoustic analysis of recorderd voices with computer program for voice analysis MDVP. Mean value of variable fundamental frequency of male subjects from control group (MF0) was 113,43 Hz, and for female subjects it was 200,71 Hz, which is in accordance with mean fundamental frequency characteristic for males and females in general. Typical values of mean fundamental frequency obtained for man is 120 Hz, and for women is 220 Hz (15). Obtained different values of fundamental frequency between male and female subjects are quite normal, because fundamental frequency represent the main acoustic parameter for differentiation between male and female voices (16). We obtained higher values of fundamental frequency for male subjects with multiple sclerosis (MF0 – 152,80 Hz), whereas for female subjects with multiple sclerosis we obtained lower values of fundamental frequency (FF0 – 165,45 Hz) compared to mean values of F0 from control group.

Mean value for standard deviation of fundamental frequency was higher in subjects with multiple sclerosis (17,03), whereas in subjects from control group this value was significantly lower (5,02). Mean value of phonatory F0 range in semitones (PFR) was also higher in subjects with multiple sclerosis, and it was 12,65, whereas for subjects from control group it was 6,58. Frequency tremor intensity index in Hz (FFTR) was higher in subjects with multiple sclerosis, and lower in subjects from control group. Additionally, values for amplitude tremor frequency (FATR) were higher in subjects with multiple sclerosis, and lower in subjects from control group. A rise in pitch is directly affected by changes in length, tension and cross-sectional mass of the vocal folds. Increased tension and stiffness of vocal fold result in an increase of vibratory frequency, and is heard as a rise in pitch (17). Jitter and shimmer are voice acoustic features often used for the description of pathological voice quality (18). Variable jitter is related to pitch perturbation and is expressed in %. The normal level of jitter is 1% (19). Mean value of jitter in subjects with multiple sclerosis was 2,40%, and is higher than typical value of jitter, whereas in subjects from control group jitter value did

not exceed 1% (it was 0,98%). Authors who deal with these issues report significantly higher correlation between jitter and voice hoarseness (or harshness) (20). Higher values of jitter reduce voice quality (21). Mean value of coefficient of variation of the fundamental frequency (vF0) was higher in subjects with multiple sclerosis (9,39%), and lower in subjects from control group (2,98%).

Shimmer in dB provides evaluation of cycle-to-cycle amplitude variations within the analyzed voice sample. During normal phonation, the variation around the mean amplitude is not usually greater than 0.5 dB or 5% of the voice signal (17). Higher value of shimmer in voice signal is perceived as hoarseness, and shimmer represent one of the most reliable acoustic predictors of dysphonia severity (22).

Mean value of short-term perturbation of amplitude in the vocal tone (in dB–Shimmer) was higher in subjects with multiple sclerosis (0,79dB). In subjects from control group that value was 0,64 dB. Therefore, in both groups mean values of shimmer are higher than established norm. Respiratory insufficiency and reduced phonatory function result in an rise of shimmer values which depicts decreased voice quality. Perturbation in amplitude of the vocal tone was confirmed through variable related to peak-to-peak amplitude variation (vAm) in subjects with multiple sclerosis (36,66%), and this value was 24,66% in subjects from control group. Researches indicate that increased values of parameters measuring frequency and amplitude perturbations correlate significantly with perceived diminishing of voice quality (17). Dogan, Midi, Yazici et al (2007) in their comparative, controlled, cross-sectional study evaluated the voice quality in patients with multiple sclerosis (MS) by subjective and objective methods. Acoustic analysis and subjective measurements (GRBAS and "Voice Handicap Index") were used in their study. They have discovered that values in variables jitter percent, shimmer percent, and soft phonation index (SPI) were higher in MS patients compared to controls (Jitt, P=0.001; Shim, P=0.033; SPI P<0.0001) (23).

Evaluation of irregular vocalization revealed differences between examined groups. We obtained higher degree of irregular vocalization (DUV) in subjects with multiple sclerosis (8,91%), and it was significantly lower in subjects from control group (1,68%). In patients with multiple sclerosis, loss of voice loudness control, diminished frequency and voice quality usually result in voice hoarseness (24).

Mean value for amplitude tremor frequency (FATR) was higher in subjects with multiple sclerosis (12,58%), and significantly lower in subjects from control group (4,68%). Subjects with multiple sclerosis had greater number of voice breaks (3,24), and subjects from control group had only 0,13 breaks during phonation.

T-test was used for examination of differences between subjects who suffer from multiple sclerosis and control group in variables determining voice acoustic characteristics. Results of the study revealed statistically significant differences between subjects with multiple sclerosis and subjects from control group in variables standard deviation of fundamental frequency (STD: p<0,020) and phonatory F0 range (PFR: p< 0,004). We also determined statistically significant differences between variables related to pitch perturbation (JITTER: p<0,002 and vF0: p<0,009), and variables related to variation in peak-to-peak amplitude (vAM: p<0,013). Additionally, we determined statistically significant differences between subjects with multiple sclerosis and subjects from control group in variables related to degree of irregular vocalization (DUV: p<0,031), variable noise to harmonic ratio (NHR: p<0,021) and variable amplitude tremor intensity index (ATRI: p<0,001). Results suggest that phonation processes in individuals with multiple sclerosis differ from those processes in individuals without MS. In the study of Dogan et al. (2007) it was determined that value for noise to harmonic ratio (NHR) was similar for MS and control group (NHR, *P*=0.737) (23).

Group of authors have conducted research in the purpose of comparison quantitative acoustic parameters in multiple sclerosis patients and normal individuals. They have discovered that fundamental frequency deviation was significantly higher in MS women (but not men) than controls (p=0.00). Jitter was higher in MS men than in all other groups (p=0.00). Results suggest that evaluation and treatment of MS patients should be revised, evaluating voice alterations in relation to other signs. MS seems to intensify gender effect on fundamental frequency deviation, noise, and jitter, with MS women presenting fewer voice variations than men (25). Hartelius, Buder and Strand 1997 used a new approach to describe and quantify the long-term phonatory instability of speakers with MS. The phonations were F0 and intensity analyzed and subjected to spectral analysis using the Fast Fourier Transform. Three methods for analyzing the instabilities are presented, compared, and related to perceptual judgments: coefficients of variation, magnitude-based analysis of spectral energy, and frequency-based analysis of spectral components. All measures reliably distinguished between individuals with MS and persons with normal speech (26).

5. CONCLUSION

Conducted study has shown that subjects with multiple sclerosis exhibit significant variability in variables pertaining to pitch perturbation and peak-to-peak amplitude variation, voice quality and presence of tremor compared to control subjects. MDVP can provide precious data on voice acoustic characteristics of individuals with multiple sclerosis during initial evaluation of voice parameters directly after establishing diagnosis of multiple sclerosis, and it can also enable monitoring of improvement of above mentioned voice parameters after application of medical and logopedic treatments.

REFERENCES

1. Renom M, Ganty G, Hartelius L, Lafortune, M, Nota A. Warinowski EL Assessment of Communication Abilities In MS.: "http://www.uninet.edu/union99/congress/confs/em/02Renom.htm l1999".
2. Sandyk R. Resolution of dysarthria in multiple sclerosis by treatment with weak electromagnetic fields. International Journal of Neuroscience. 1995; 83: 81-92.
3. Hartelius L, Runmarker B, Andersen O. Prevalence and Characteristics of Dysartria in a Multiple-sclerosis incidence cohort: relation to Neurological data. Folia Phoniatrica et Logopedica. 2000; 52: 160-177.

4. Brown S. Swallowing and Speaking-Challenges for the MS Patient. International Journal of MS Care. 2000; 2: 2-12.
5. Merson RM, Rolnick MI. Speech-language pathology and dysphagia in multiple sclerosis. Phys Med Rehabil Clin N Am. 1998; 9(3):631-41.
6. Freed D. Motor Speech Disorders: Diagnosis and Treatment. San Diego, USA: Singular Thomson Learning; 2000.
7. Miller Sorensen P. Speech and voice disorders. In RC Kalb. Multiple sclerosis. The Questions you have The answers you need 3rd ed., New York: Demos Medical Publising LLC; 2004.
8. Hartelius L, Runmarker B, Andersen O, Nord L. Temporal speech characteristics of individuals with multiple sclerosis and ataxic dysarthria: 'scanning speech' revisited. Folia Phoniatrica et Logopedica. 2000; 52: 228-238.
9. Boon DR. Management of voice disorders in adults. Seminars in Speech and Language, Thieme-Stratton, In., N.Y.; 1983: 259-273.
10. Violette J. Multiple Sclerosis and the Role of the Speech-Language Pathologist. "http://www.imssf.org/speechpathology.shtml 2001.
11. Andrews ML. Manual of Voice Treatment: Pediatrics through Geriatrics, Andrews M. Ed. 3rd Edition, Thomson Delmar Learning; 2006.
12. Baken RJ Clinical Measurement of Speech and Voice. San Diego, London: Singular Publishing Group, Inc.; 1996.
13. Parsa V, Jamieson DG. A Comparison of High Precision Fo Extraction Algorithms for Sustained Vowels. Journal of Speech and Hearing Research. 1999; 42: 112-126.
14. Deliyski DD. Acoustic Model and Evaluation of Pathological Voice Production. Paper presented at Eurospeech. Berlin, Germany; 1993.
15. Heđever M. Akustička analiza vremenskih segmenata normalnog i poremećenog govora. Doktorska disertacija, Edukacijsko-rehabilitacijski fakultet, Zagreb; 1996.
16. Andrews ML. Manual of Voice Treatment: Pediatrics through Geriatrics, Andrews M. Ed. 3rd Edition, Thomson Delmar Learning, 2006.
17. Dworkin JP, Meleca RJ. Vocal pathologies: diagnosis, treatment, and case studies. San Diego, London: Singular Publishing Group, Inc., 1996.
18. Michaelis D, Fröhlich M, Strube H W, Kruse E, Story B, Titze IR. Some simulations concerning jitter and shimmer measurement. In: Advances in Quantitative Laryngoscopy, Voice and Speech Research. Proc. 3rd International Workshop, June 19-20 1998), hrsg. v. T Lehmann et al.; Aachen : Universitätsklinikum, RWTH, 1998; 71-80.
19. Jacobson BH. The Clinical Voice Laboratory. U Benninger MS, Jacobson BH, Johnson AF. Vocal Atrs Medicine, The Care and Prevention of Profess. Voice Disorders. Thieme Medical Publishers, Inc. New York, 1994: 135-152.
20. Bolfan-Stošić N. Akustičke karakteristike glasa djece s Downovim sindromom, oštećenjima sluha, cerebralnom paralizom, disfonijama i djece bez oštećenja (Acoustic characteristics of voice in children with Down syndrom, hearing disorder, cerebral palsy, dysphonia and children without disorders). Doktorska disertacija, Edukacijsko-rehabilitacijski fakultet, Zagreb; 1999.
21. Prizl-Jakovec, T., Brestovci, B. Fonacija osoba sa afazijom (Phonation in persons with aphasia). Hrvatska revija za rehabilitacijska istraživanja 2001; 37: 171-177.
22. Wolfe V, Fitch J, Cornell R. Acoustic prediction of severity in commonly occurring voice problems. Journal of Speech and Hearing Research. 1995; 38: 273-279.
23. Dogan M, Midi I, Almaz Yazıcı M, Kocak I, Günal D, Sehitoglu M A. Objective and Subjective Evaluation of Voice Quality in Multiple Sclerosis. Journal of Voice. 2007, 21 (5): 735-740.
24. Colton R. Physiology of voice quality. In: WS Brown, BP Vinson, MA Crary (Eds.), Organic voice disorder, San Diego, London: Singular Publishing Group, Inc., 1996.
25. Vélez Feijó A, Parente MA, Behlau M, Haussen S, De Veccino MC, Castellar B, Martignago F. Acoustic analysis of voice in multiple sclerosis patients. Journal of Voice. 2004; 18: 341-347.
26. Hartelius L, Buder EH, Strand EA. Long-term phonatory instability in individuals with multiple sclerosis. Journal of Speech, Language and Hearing Research. 1997, 40(5):1056-72.

Corresponding author: Mirela Duranovic, MD. E-mail: mirela.duranovic@bih.net.ba, phone: + 387 35 320 671