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ACOUSTIC ANALYSIS OF VOICE AND SPEECH IN ADULTS WITH SPASTIC DYSARTHRIA

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SUMMARY

Spastic dysarthria as a motor speech disorder impairs the intelligibility of speech production. By perceptual evaluation in individuals with this type of dysarthria, disorders of articulation, tense phonation, impaired prosody and nasalization, monotonous production and slow and difficult speech are observed. Acoustic analysis can provide quantitative data on the deviation of speech and voice characteristics of individuals with dysarthria compared to typical speakers.

The goal of this research was to determine the values of acoustic parameters of voice and speech in adults with spastic dysarthria compared to those values in typical speakers. The analysis was performed by using the Multidimensional Voice Program (MDVP) based on continuous phonation of vowel /a/ and speech patterns obtained by reading Balanced Text. The sample consisted of 36 individuals with spastic dysarthria, of whom 20 (55.6%) were men and 16 (44.4%) were women, aged 22 to 87 (M = 61.7).

The results showed that the majority of the twelve acoustic voice parameters tested in individuals with spastic dysarthria showed statistically significant deviation from the norms applicable to typical speakers. The acoustic parameters examined included those indicating variability of fundamental frequency, variability of amplitude, presence of noise, irregularities and interruptions in voice. Also, spectral analysis indicated statistically significant deviations in the position of the formants of vowels /e/ and /i/, as well as the occurence of centralization of the vowel formants, which together indicate impaired intelligibility of speech production.

Acoustic analysis of speech of individuals with spastic dysarthria provided data indicating a serious pathology of their voice and speech. Such data are very useful because they make it easy to determine the appropriate treatment, managing the patient during the treatment, and also conducting the evaluation of the treatment.

Key words: acoustic analysis, spastic dysarthria, speech, voice

INTRODUCTION

Spastic dysarthria is a motor speech disorder that results from damage to the upper motor neuron whose function is to convey impulses from the motor areas of the cortex to the lower motor neuron. It occurs within cerebral palsy and as a result of traumatic brain damage, with increased tone (spasticity or hypertonus), weakness or decreased range of voluntary limb muscle movements and the orofacial region (Kent, Duffy, Straw, Kent, & Clift, 2001). Other authors state that spastic dysarthria most commonly occurs in pseudobulbar palsy and spastic hemiplegia (Murdoch, 2014). This type of dysarthria is considered to be one of the most common in both children and adults.

Spastic dysarthria can be of different severity, with difficulty in accomplishing the process of respiration, phonation, and articulation. It is typically characterized by tense phonation, imprecise articulator placement (especially when uttering consonants), and reduction of temporal differences between speech and non-speech pauses (Hasegawa-Johnson, Gunderson, Perlman, & Huang, 2006). Speech production is further characterized by impaired prosody, prominent nasalization, and variations in speech rate, which impairs the intelligibility of speech production (Paja & Falk, 2012). Speech has been found to be generally slow and difficult (Griffiths & Bough, Jr., 1989).

Articulatory imprecision is one of the primary characteristics of this speech disorder (Marchant, McAuliffe, & Huckabee, 2008) and it occurs due to inadequate tongue and lip movements. Clark et al., (2014) noted that the following characteristics of speech were distinguished in patients with spastic dysarthria: tense voice quality, slow speech, without pitch and loudness modulation (monotonous speech), hypernasality, and speech in short phrases. Rough and strained voice quality is caused by increased vocal fold tension (hyperadduction) that occurs in people with spastic dysarthria.

Dysarthria caused by pseudobulbar palsy results in strained and rough voice, hypernasality, impaired articulation with imprecise voice production, and abrupt interruptions of phonation (Murdoch, Ward, & Theodoros, 2008), whereas in those caused by spastic hemiplegia, a milder speech disorder occurs with articulation that is slow and imprecise as the most affected (Murdoch, 2014). Bilateral damage to the upper motor neuron, either at the cortical or subcortical level, leads to syndromes typical of spastic dysarthria. Slow articulatory movements with reduced amplitude occur as well as hypernasality due to lack of adequate velum lift, tongue retraction, pharynx narrowing, and hyperadduction of shortened vocal folds (Ziegler & von Cramon, 1986). In extreme cases, complete anarthria or aphonia can occur (Ackermann, Hertrich, & Ziegler, 2010).

Acoustic analysis of voice and speech in people with dysarthria

Acoustic analysis of speech and voice is performed on the basis of continuous phonation of vowels or spontaneous speech samples on the basis of which spectrographic analysis is performed. With the help of special computer programs, the values of acoustic parameters of voice and speech are obtained as objective indicators of possible pathology of voice. Computer-based devices that enable acoustic voice processing facilitate accurate diagnosis of voice disorders, follow-up on clinical work, and reduce the degree of subjectivity that occurs during perceptual assessment (Teixeira, Ferreira, & Carneiro, 2011).

Today, acoustic analysis of voice and speech is increasingly conducted in people with dysarthria, although it is noted that not all types of dysarthria are equally represented in research (Arsenić, 2019). Dysarthria is known to be a speech disorder that results in impaired speech control mechanisms and occurs as a consequence of damage to the central or peripheral nervous system (Darley, Aronson, & Brown, 1969). The neurological dysphonias that occur within dysarthria are very important in differential diagnosis. In cases where laryngeal function is impaired as a result of neurological dysfunction, other speech components are impaired. Vowel analysis in individuals with neurological diseases can significantly contribute to early diagnosis, differential diagnosis, and monitoring of disease progression (Abberton, 2005). It allows quantification of data and a description of the correlation of perceptual assessment of speech intelligibility, quality of voice, and type of dysarthria (Carrillo & Ortiz, 2007). The basic goals of acoustic analysis are to contribute to the proper diagnosis of neurological diseases of different neurological subsystems, to identify progressive degeneration of neurological disease and to identify subclinical manifestations of neurological disease (Amir, Dukas, & Schnaps-Baum, 2005; Deliyski, Evans, & Shaw, 2005). Also today, more attention is directed towards what impact have characteristics of voice and speech in dysarthria on individuals, their feelings related to problems during the conversation and their interaction with other people and the quality of their communication (Arsenić & Jovanović Simić 2019; Arsenić, Jovanović Simić, Petrović Lazić, Šehović, & Drljan, 2019; Jovanović Simić, Arsenić, Drljan, & Milovanović, 2019).

Computer programs for voice analysis provides for more detailed and clearer description and clarification of the various voice dysfunctions in the context of speech disorders (Arsenić et al., 2019; Arsenić, Jovanović Simić, Petrović Lazić, & Šehović, 2019). One of the programs which has a clinical and research application in voice assessment in people with dysarthria is the multi-parameter acoustic voice analysis or the Multidimensional Voice Program (MDVP program by Kay Elemetrics Corporation). The program provides fast and standardized voice assessment and displays 33 acoustic parameters of the processed voice and provides a view of the analysed speech pattern in the form of a spectrogram. The obtained parameter values are compared with the reference values contained in the program, which are obtained on the basis of voice and speech analysis of typical speakers of a particular language. In analysing the data, care must be taken that there are reference values separately for men and women. In addition, the program also allows the installation of alternative normative values, for example for the elderly or children.

Acoustic voice parameters that can be obtained using a computer program for multidimensional analysis are most often divided into four groups: parameters indicating variability of voice frequency, parameters indicating variability of voice amplitude, parameters indicating interruptions in voice, presence of subharmonics, and irregularities in the voice and parameters indicating the presence of noise and tremors in the voice (Deliyski & Gress, 1998). However, this is not the only division of acoustic voice parameters. Depending on the measurement goals, there are different categorizations of MDVP parameters. Other authors (Lierde et al., 1996, according to Kent, Vorperian, Kent, & Duffy, 2003) represent eight groups of acoustic voice parameters: fundamental frequency parameters, frequency perturbation parameters, amplitude parameters, voice irregularity parameters, tremor analysis parameters, voice interruption parameters, subharmonic parameters and noise parameters.

MDVP also enables acoustic analysis of the speech signal in individuals with dysarthria, where the signal is presented through a spectrogram. It is a visual presentation of an acoustic signal in three dimensions: time, frequency and amplitude (Sovilj-Nikić, 2014). The acoustic structure of the voices of the Serbian language has three aspects: formant, noise and combined formant - noise. The formant of acoustic energy is characteristic for vowels, formant-noise form for nasals and laterals, while the noise form is related to plosives, fricatives and affricates. The first three acoustic energy concentrates for each voice individually are the most important for auditory voice discrimination. The values of formats of all voices are the same for men and women and do not depend on the height of the basic laryngeal tone.

The goal of the research was to determine the acoustic characteristics of voice and speech in adults with spastic dysarthria. It was examined whether the values of the acoustic parameters of the voice and the values of the vowel formants significantly deviate from the norms applicable to typical speakers of Serbian.

METHOD

The sample consisted of 36 individuals with spastic dysarthria, of whom 20 (55.6%) were men and 16 (44.4%) were women, aged 22 to 87 (M = 61.7). The respondents native language was Serbian and they did not have associated disabilities that could affect speech and voice characteristics.

The research was conducted at the Rehabilitation Clinic "Dr Miroslav Zotović" and the Special Hospital for Cerebrovascular Diseases "St. Sava" in Belgrade, while the data were processed and analysed at the Clinical-Hospital Center "Zvezdara" in Belgrade. The test was conducted individually, in a quiet room, isolated from noise. Voice and speech were recorded with a voice recorder at a distance of 5 cm from the mouth.

The instruments used in the research are:

1. *The computerized speech laboratory for acoustic analysis of voice and speech of "Kay Elemetrics" corporations, model 4300* – by using the program for multidimensional voice analysis (MDVP), the values of 12 acoustic parameters were determined based on the continuous phonation of vowell /a/. The respondents were tasked with producing this vowel at the usual volume and height for 3 to 5 seconds. As the acoustic characteristics of the male and female voice differ, the analysis was conducted separately for both sexes.

2. *Balanced Text (Šešum, 2013)* - Spectral analysis of vowels was performed with the help of multidimensional voice analysis software. Five vowels in the Serbian language were analyzed on the basis of a speech sample obtained by respondents reading "Balanced Text", which was specifically designed for the speech analysis. The text itself is a coherent semantic whole and contains complex statements that are grateful for speech analysis. In the text, the representation of all voices is as uniform as in everyday speech. Spectral analysis determined the position of the first and second formants (F1, F2) for each vowel.

Out of 12 acoustic voice parameters, six indicate fundamental frequency variability (Fo, MFo, Fhi, Flo, Jita, Jitt), two parameters represented the variability of voice amplitude (ShdB, Shim), two the presence of noise in the voice (NHR, SPI), and two presence of irregularities and interruptions in the voice (DVB, DUV).

Parameters indicating fundamental frequency variability are: ***Fo*** - Average Fundamental Frequency /Hz/ corresponding to the number of vibratory vocal fold cycles per second (Carrillo & Ortiz, 2007). In addition to fundamental frequency there are ***MFo*** - Mean Fundamental Frequency /Hz/, ***Fhi*** - Highest Fundamental Frequency /Hz/ and ***Flo*** - Lowest Fundamental Frequency /Hz/. Increased *MFo* values indicate pathological conditions due to shortening of the vibratory zones of the vocal cords, increased stiffness of the mucosa, a decrease in the mass of the vocal cords, or an increase in subglottic pressure. Decreased values of the *MFo* parameter occur due to an increase in the mass of the vibrating structure or a decrease in laryngeal position (Deliyski & Gress, 1998).

The perturbation parameters of voice frequency (***Jitter***) and amplitude (***Shimmer***) are used to test speech intelligibility and are most commonly used when describing pathological voice. Both of these parameters can be determined using the relative values of ***Jitt*** /%/ and ***Shim*** /% / or absolute values of ***Jita*** /µs/ and ***ShdB*** /dB/ (Teixeira & Gonçalves, 2014).

NHR (Noise to Harmonic Ratio) is a parameter indicating the range between periodic (harmonic) and aperiodic (noise) components and most commonly indicates increased noise occurring at the glottis level (Buder, 2000), and the ***SPI*** (Soft Phonation Index) parameter is an indicator of how much the vocal cords close and tighten during phonation. An increased value of the *SPI* parameter is usually an indicator of insufficiently tightened and incompletely closed vocal cords during phonation (Deliyski & Gress, 1998).

DVB - Degree of Voice Breaks /%/ represents the ratio between the total duration of parts with interruptions in the voice and the duration of the complete voice sample, more precisely it represents the percentage of parts with interruptions in voice. ***DUV*** - Degree of Voiceless /%/ measures the voice's ability to last continuously. The normative threshold for both parameters is 0 (zero) because normal voice in certain voice maintenance tasks should not have any segments without voice or interruption of voice (Deliyski & Gress, 1998).

Statistical processing and analysis of data was performed in the statistical package SPSS 24. Frequencies, percentages and sample mean (arithmetic mean) were used as descriptive statistics measures. Standard deviation was used as a measure of deviation from the arithmetic mean. The probability level was set at $p < 0.05$. Differences of sample values with respect to norms were tested by t test for one sample.

RESULTS WITH DISCUSSION

Acoustic analysis of voice

Many authors (Heman-Ackah et al., 2003; Maryn, Roy, De Bodt, Van Cauwenberge, & Corthals, 2009; Teixeira & Fernandes, 2014) state that in the acoustic analysis of voice using MDVP, the attention is most commonly paid at the values of fundamental frequencies parameters (*Fo*), *NHR* parameter (noise-harmonic ratio), *jitter* and *shimmer* perturbation parameters, and the range of fundamental frequency. The *jitter*, *shimmer*, and *NHR* parameters are cited as the cornerstone of acoustic measures of voice signal and are most commonly regarded as indicators of perceived voice quality in both normal and pathological voice (Kreiman & Gerratt, 2005).

As expected, the values of a large number of acoustic voice parameters in individuals with spastic dysarthria differed from the norms applicable to typical speakers. Even most of the acoustic parameters were statistically significantly different (Table 1).

Table 1. *Average values of acoustic parameters and differences compared to normal values, male*

	Male		t	df	p
	M	**SD**			
Fo	153.611	35.229	1.064	19	0.301
MFo	140.196	21.488	-0.322	19	0.751
Fhi	297.227	164.570	3.999	19	***0.001***
Flo	96.982	24.152	-8.043	19	***0.000***
Jita	501.510	422.826	4.864	19	***0.000***
Jitt	7.026	5.952	4.837	19	***0.000***
ShdB	1.560	0.714	8.392	19	***0.000***
Shim	16.488	6.813	9.166	19	***0.000***
NHR	0.458	0.229	6.558	19	***0.000***
SPI	4.454	1.985	-5.217	19	***0.000***
DVB	10.835	19.050	2.497	19	***0.022***
DUV	47.729	33.120	6.418	19	***0.000***

M – arithmetic mean, SD-standard deviation, t – t test for one sample,
df – degrees of freedom, p – statistical significance

Table 1 shows that the voice of male individuals with spastic dysarthria is significantly altered compared to that of typical speakers. Most of the values of the acoustic parameters are statistically significantly different from the norms, except for the parameter *Fo* which is slightly higher and *MFo* which is slightly lower. Among the parameters that showed a statistically significant difference from the norms, *Flo* and *SPI* were lower, while all other parameters were statistically significantly higher than the norms applicable to typical male speakers.

Most of the acoustic parameters of the voice of women with spastic dysarthria are also statistically significantly different from the norms applicable to female speakers who are typical speakers (Table 2).

Table 2. *Average values of acoustic parameters and differences compared to normal values, female*

	Female		t	df	p
	M	**SD**			
Fo	169.900	56.324	-5.261	15	***0.000***
MFo	167.060	56.803	-5.212	15	***0.000***
Fhi	259.303	141.020	0.187	15	0.854
Flo	136.432	59.963	-6.566	15	***0.000***
Jita	353.740	448.538	2.914	15	***0.011***
Jitt	4.706	4.717	3.454	15	***0.004***
ShdB	1.356	1.024	4.609	15	***0.000***
Shim	13.583	9.404	4.928	15	***0.000***
NHR	0.414	0.309	3.907	15	***0.001***
SPI	4.841	1.394	-7.730	15	***0.000***
DVB	4.996	8.672	2.212	15	***0.043***
DUV	32.186	33.683	3.799	15	***0.002***

M – arithmetic mean, SD-standard deviation, t – t test for one sample,
df – degrees of freedom, p – statistical significance

There is no difference only on the parameter *Fhi* which is slightly higher than the norms. Among the parameters showing statistically significant difference, *Fo*, *MFo*, *Flo* and *SPI* have lower values compared to the norms, while the values of all remaining parameters are higher.

It can be seen that the values of the *Flo* and *SPI* acoustic parameters are statistically significantly lower than the norms for both sexes, while most of the remaining parameters for both respondents are statistically significantly higher than the standards existing for typical speakers. An increased value of the *SPI* parameter is usually an indicator of insufficiently tightened and incompletely closed vocal cords during phonation. Still, it does not have to indicate a voice disorder. Similarly, patients with inadequate phonation may have a "normal" value of this parameter, although such a voice characteristic may be undesirable. Therefore, the high value of this parameter does not have to be bad, nor does the low value of the *SPI* parameter need to be good (Deliyski & Gress, 1998).

As in many previous researches with all types of dysarthria, our research showed in individuals with spastic dysarthria that the values of the *jitter* and *shimmer* parameters were always increased. These values are known to be elevated in neurogenic dysphonias because they indicate irregularity of vocal cords vibration as a result of reduced neuromuscular control of laryngeal abductors and adductors (Carrillo & Ortiz, 2007). Fundamental frequency values in respondents with dysarthria are characterized by an excessive amount of *jitter* voice acoustic parameter (Kain, Niu, Hosom, Miao, & Santen, 2004), and the fundamental frequency range is narrower than in the control group respondents (Mori, Kobayashi, Kasuya, Hirose, & Kobayashi, 2004).

Increased *NHR* parameter values also found in the sample of respondents with spastic dysarthria are interpreted as increased spectral noise, which may be caused by variations in amplitude and frequency, presence of turbulent noise, subharmonic components or interruptions in voice, all of which indicate pathology of voice and impaired speech intelligibility. The noise present in the spoken vowel spectrum gives the voice a specific colour, that is, roughness if present to a greater extent and degrades the quality of the vowel (Antić, Šagovnović, & Popović, 1997).

The *DVB* and *DUV* parameters are statistically significantly higher than the norms. Such results indicate that a large number of interruptions in the voice as well as periods without voice occur in individuals with spastic dysarthria, which indicates a very difficult speech of these persons as well as impaired intelligibility of speech production.

More recent research (Giri & Rayavarapu, 2018) examined the values of the acoustic parameter *MFo* for individuals with dysarthria of flaccid, spastic and hypokinetic type. The acoustic characteristics of individuals with and without dysarthria, men and women separately, were compared. A male respondent with spastic dysarthria achieved an *MFo* value of about 156 Hz, which is higher than that in typical male speakers. In our research, the average values of the *MFo* parameter were slightly lower (without statistical significance) in a sample of 36 respondents. It is important to note that the main drawback of the research is that it was performed on one respondent in each type of dysarthria.

In another research (Mori et al., 2004), the values of the acoustic parameters of the voice of respondents with different types of dysarthria were compared. Sixteen male patients were examined, of whom 5 were respondents with pseudobulbar palsy (spastic dysarthria), 7 with Parkinson's disease (hypokinetic dysarthria) and 4 with ALS (spastic-flaccid dysarthria). The sample was compared with six male individuals from the control group. The research examined the fundamental frequency of voice (*Fo*) as well as the minimum of fundamental frequency (*Flo*). The results showed that the *Fo* range in respondents with dysarthria was narrower than that in the control group, indicating that their intonation pattern was flattened. A flattened intonation pattern is observed to be a general characteristic of dysarthria while fundamental frequency values differ among types of dysarthria. In individuals with spastic-flaccid dysarthria due to muscular weakness, the tension in the vocal folds is reduced, resulting in lower levels of *Fo*. In individuals with spastic dysarthria, the values of fundamental frequencies are different depending on whether there is hypertension or hypotension of the vocal cords (Mori et al., 2004). Thus, in our research, in the male respondents, the values of the *Fo* parameter were on average slightly higher than typical male speakers, while the values of this parameter were statistically significantly lower in the female respondents than in the typical female speakers.

Another research (Dogan, Midi, Yazıcı, Kocak, Günal, & Sehitoglu, 2007) examined the speech of 27 female patients with dysarthria suffering from multiple sclerosis. Patients with multiple sclerosis most often have spastic and ataxic dysarthria. Changes in voice in these individuals are characterized by impairment of voice control and the presence of roughness in the voice. Less common problems are impaired voice control, inadequate voice height, shortness of breath, and hypernasality. The computer voice analysis (MDVP) was used to evaluate the vowel /a/ to obtain the values of acoustic parameters: *Jitt*, *Shim*, *SPI*, *NHR* and *MFo*. The acoustic parameters of *Jitt*, *Shim* and *SPI* were higher in female respondents with multiple sclerosis compared with female respondents in the control group. The *NHR* and *MFo* values were similar in dysarthria patients and control group. Most patients with multiple sclerosis had dysphonic speech that was due to weakness of voice. These patients tend to be aggravated by the following acoustic parameters: *Fo*, *SPI* and jitter. These results are consistent with the asthenic voice quality that occurs in individuals with multiple sclerosis. In our research, although there was no sample of respondents with multiple sclerosis, the results of the indicated values of acoustic parameters can be compared to the results on the sample of respondents with spastic dysarthria. As in the aforementioned research, in ours, the values of the *Jitt* and *Shim* parameters were statistically significantly higher than the norms applicable to women, while the value of the *SPI* parameter was lower than the norms, indicating a partial overlapping of the results.

Spectral analysis of vowels

Acoustic processing is also performed on the sample of spontaneous speech of respondents or their speech during reading (Buder, 2000). Spectral analysis usually determines the positions (frequency) of the first and second formants for all vowels or noise concentrate for some consonants. Spectral analysis can objectively determine the voice quality and describe the texture of phonation.

In this research, the position of the first two formants of all five vowels in the Serbian language in adults with spastic dysarthria was examined. The position of the first two formants determines the intelligibility of individual voices, and therefore the intelligibility of spoken production.

Table 3 shows the obtained values of the first and second formants of five Serbian vowels for persons with spastic dysarthria. The differences between the values achieved on the sample and the norms applicable to typical speakers were also examined. Differences were tested by t test for one sample.

Table 3. *Average values of formants and differences compared to normal values*

		N	Min	Max	M	SD	t	df	p
A	**F1**	36	448.000	842.000	658.972	110.453	0.487	35	0.629
	F2	36	926.000	1614.000	1301.944	172.176	-0.106	35	0.916
E	**F1**	36	418.000	662.000	514.028	77.365	-0.075	35	0.940
	F2	36	1016.000	2332.000	1636.250	335.994	18.505	35	***0.000***
I	**F1**	36	179.000	807.000	381.333	120.703	4.043	35	***0.000***
	F2	36	896.000	2601.000	1892.889	546.275	-2.275	35	***0.029***
O	**F1**	36	328.000	687.000	510.917	84.632	-0.077	35	0.939
	F2	36	747.000	1204.000	994.250	119.517	-0.038	35	0.970
U	**F1**	35	180.000	687.000	379.171	116.857	0.161	34	0.873
	F2	35	508.000	1315.000	843.371	180.732	1.420	34	0.165

N - number of respondents, Min - minimum value on the sample, Max – maximum value on the sample,
M – arithmetic mean, SD-standard deviation, t – t-test, df – degrees of freedom, p – statistical significance

A statistically significant difference between sample values and norms was determined for the first and second formant (F1, F2) of vowel /i/ ($p < 0.001$; $p < 0.05$) and the second formant (F2) of vowel / e/ ($p < 0.001$).

F1 values of vowel /i/ in typical speakers range between 170 and 300 Hz, and the average sample value obtained is higher and it is M = 381,333 Hz. The second formant (F2) of vowel /i/ has a normal value of 2100 to 2500 Hz, and the achieved value on the sample of people with spastic dysarthria is lower than the norm and it is M = 1892,889 Hz. F2 value of vowel /e/ in typical speakers ranges from 1720-2000 Hz, while the sample values are lower (M = 1636,250). Based on the above stated results, it can be observed that in persons with spastic dysarthria the centralization of the vowel formats was confirmed.

The results of our research showed that production of vowels in respondents with spastic dysarthria was characterized by centralization of the formant frequency and reduction of vowel range. Kent et al., (Kent, Vorperian, & Duffy, 1999) cite the same data indicating this specificity in the speech of individuals with dysarthria and state that reduced vowel space in dysarthria has a negative effect on intelligibility. Reduced vowel space which results from the increase of the otherwise low frequencies of the formats and the decrease of the otherwise high frequencies of the formats. Such changes in formant position are thought to be due to limited articulator movements, especially the tongue and jaw (Skodda, Grönheit, & Schlegel, 2012). Individuals with dysarthria make mistakes while articulating vowels and consonants. Also, in their speech there is often a pronounced nasality and prolongation of segments. All of the above stated disturbs the patterns of speech accentuation and causes the speech of people with dysarthria to be extremely slow and difficult (Duffy, 2005).

The "formant centralization ratio" measure is cited in a paper that examined the difference in speech between that of individuals with dysarthria and typical speakers (Sapir, Ramig, Spielman, & Fox, 2010). These authors argue that the measure clearly distinguishes between these two groups of persons, and that it represents a sensitive, valid and reliable acoustic measure for monitoring the effects of treatment. Although these results were obtained from a sample of individuals with hypokinetic dysarthria, the authors state that they can be applied to dysarthria resulting from multiple sclerosis, amyotrophic lateral sclerosis, cerebral palsy and traumatic brain damage. Most commonly, the first two formants (F1 and F2) are used for acoustic assessment of vowel production and perception (Hillenbrand, Getty, Clark, & Wheeler, 1995). The centralization of vowel formants is thought to be due to irregular movements of the articulators during their production. The range of articulatory movements has been reduced, so formants that otherwise have a lower frequency become higher and higher formants become lower. Such centralization can be represented through the vowel space area, i.e. the space between the first and the second formant. The greater the centralization, the smaller the vowel space.

Also, a study examining the speech of individuals with mixed dysarthria and dysarthria due to traumatic brain damage (Toshniwal & Joshi, 2010) examined the space area (between F1 and F2) for four vowels. It was found that in individuals with dysarthria due to traumatic brain damage, the vowel space area was reduced (F1 and F2) compared to respondents in the control group. Such reduced vowel space area indicates the presence of deviation in the exercise of articulatory movements in individual with traumatic brain damage.

A more recent study (Fougeron & Audibert, 2011) examined the acoustic characteristics of the voice of respondents with amyotrophic lateral sclerosis diagnosed with a mixed dysarthria (spastic-flaccid). This type of dysarthria is thought to have the greatest damage to the vowels compared to all other types. Abnormal frequency of the first and second formants (F1 and F2), reduced formant transition and reduced vowel space area were found to be present in ALS (Turner & Tjaden, 2000). The study examined 27 patients with ALS. It turned out that in male individuals, the more severe the degree of dysarthria and the incomprehensible speech, the smaller the vowel space area and the greater the overlap in the F2 position for the vowels /e/ and /o/. Also, in female individuals, the less comprehensible the speech, the smaller the vowel space area was, with the centralization of the vowels. When the male individuals with mixed dysarthria were compared with the control group of the respondents, it was found that there was a significant difference between the two groups in almost all the aspects related to the position of the formant. Male individuals with dysarthria had significantly smaller vowel space area, greater formalization of formats, reduced range of first and second formants (F1 and F2), and much more overlap in vowel pairs in first and second formants. There was only one statistically significant difference in women with dysarthria compared to those in the control group, i.e. there was significantly more overlapping in the F2 position in women with dysarthria, and that for middle vowels compared to the control group. The authors state that although altered vowels can be good predictors of speech intelligibility, they are not the only predictors.

Speech of individuals with dysarthria resulting from amyotrophic lateral sclerosis was analysed in a study by Horwitz et al (Horwitz-Martin et al., 2016). It was examined what acoustic parameters could indicate a loss of speech intelligibility and a decrease in speech rate in these respondents. The sample consisted of 34 people with ALS (16 men and 18 women). The results showed that there was a correlation between F1 and F2 on the one hand and the speed and intelligibility of speech on the other. Speech rate has been found to decrease over time in people with ALS and speech becomes more incomprehensible, which is associated with the frequency of formats (Horwitz-Martin et al., 2016). The dysarthria resulting from amyotrophic lateral sclerosis is also thought to be particularly reduced in the path (position) of the second formant (F2) (Weismer, Martin, Kent, & Kent, 1992).

Inadequate articulation of vowels is a common occurrence in all types of dysarthria, which result in large variations in the frequencies of formats, as well as in the centralization of formats. Changes in vowel space area, shallower vowel gradients, and variability in vowel transition also occur (Caballero-Morales, 2013). Given that the production of consonants requires much finer and more precise movements, this group of voices is even more damaged in individuals with dysarthria, and especially those involving friction. In these individuals, the height and volume of the voice are most often reduced, whereby acoustic parameters such as the fundamental frequency, duration, amplitude and quality of parts of the statement are impaired.

In the previously mentioned study (Giri & Rayavarapu, 2018), the position of the first three formants of the vowel /a/ in individuals with dysarthria of flaccid, spastic and hypokinetic type was examined in addition to the value of the acoustic parameter of the voice *MFo*. In male respondents with spastic dysarthria, male respondents with hypokinetic dysarthria, and female respondents with flaccid dysarthria, the values of the first three formats were slightly higher compared to typical speakers.

As it was found that there was a relationship between the position of the second formant of the vowel and the perceptual characteristics, we began to examine the influence of inadequate formant values on speech intelligibility in individuals with dysarthria. Thus, a significant correlation was found between F2 position for two vowels and sentence intelligibility in individuals with dysarthria resulting from amyotrophic lateral sclerosis (spastic or flacid dysarthria) and Parkinson's disease (hypokinetic dysarthria) (Weismer, Jeng, Laures, Kent, & Kent, 2001) and the link between the second formant and speech intelligibility in individuals with dysarthria as a consequence of Parkinson's disease and stroke (Kim, Weismer, Kent, & Duffy, 2009).

In people with dysarthria, it is stated that the range of fundamental frequency, the pitch of the second formant and the vowel space area contribute to the classification according to the severity of the speech disorder (Kim, Kent, & Weismer, 2011).

CONCLUSION

Acoustic analysis of voice and speech is a modern method of assessment, which is increasingly performed independently when diagnosing dysphonia and speech disorders of different types. Also, the application of computer programs in the analysis of voice and speech disorders is used as a complement to perceptual assessments that provide subjective data.

A review of the studies related to the acoustic analysis of voice and speech in individuals with dysarthria revealed that the majority were conducted in individuals with hypokinetic, ataxic and mixed dysarthria, while very few studies had a sample of people with spastic dysarthria. This data is unusual because it has been confirmed that spastic dysarthria is the most common among different types of dysarthria. Spastic dysarthria is characterized by slow and impaired speech due to spasticity or hypertonicity, which also affect the processes of respiration and phonation, as well as the reduced range of voluntary movements that impairs articulation. In addition, in individuals with spastic dysarthria, the prosody and intelligibility of speech production are severely impaired.

As shown in our research, by acoustic analysis of the voice of individuals with spastic dysarthria, results were obtained indicating statistically significant deviations of the values of acoustic parameters compared to norms. Such objective data facilitates the determination of adequate speech therapy, which may be directed to the rehabilitation of certain acoustic parameters of the voice. In addition, statistically significant variations in the position of the formats for some vowels were determined by spectral analysis of the voice. Difficulties in articulation are most noticeable in individuals with spastic dysarthria during the production of consonants, but as confirmed here, vowel articulation can also be problematic. Obtained objective data, which have been compared with the results of other studies, clearly indicate the nature and severity of voice and speech pathology in individuals with spastic dysarthria.

Thanks to acoustic analysis of voice and speech, which enables to obtain quantitative values of acoustic parameters of the voice and voice formants, it is possible to detect the pathology of the voice, possible changes in the vocal cords, early diagnostics, differential diagnosis, as well as clear and detailed determination of differences between the characteristics of normal and pathological voice (Teixeira & Fernandes, 2014). In addition, this type of analysis has many advantages as it facilitates to determine the appropriate treatment for each patient individually, evaluate the treatment, as well as to evaluate the improvement of voice and speech after the treatment.

REFERENCES

1. Abberton, D. E. (2005). Phonetic considerations in the design of voice assessment material. *Logopedics Phoniatrics Vocology*, *30*(3-4), 175-180.
2. Ackermann, H., Hertrich, I., & Ziegler, W. (2010). 16 Dysarthria. *The handbook of language and speech disorders*, *28*, 362.
3. Amir, O., Dukas, M., & Shnaps-Baum, R. (2005). The effect of a 'voice course'on the voices of people with and without pathologies: preliminary observations. *Logopedics Phoniatrics Vocology*, *30*(2), 63-71.
4. Antić, B., Šagovnović, D., & Popović, M. (1997). Kvalitet vokala – individualna karakteristika govornika. *XLI Konferencija za ETRAN* , sveska II, 585-588, Zlatibor.
5. Arsenić, I. (2019). Karakteristike govora i glasa kao prediktori kvaliteta komunikacije odraslih osoba sa dizartrijom. *Doktorska disertacija.*
6. Arsenić, I., & Jovanović-Simić, N. (2019). Samoprocena stepena hendikepa osoba sa hipokinetičkom dizartrijom, *Dani defektologa Srbije*, (str. 112), Zlatibor 21-24.02.2019.
7. Arsenić, I., Jovanović Simić, N., Petrović Lazić, M., & Šehović, I. (2019). Prisustvo tremora u glasu odraslih osoba sa hipokinetičkom dizartrijom. U V. Žunić Pavlović, A. Grbović, & V. Radovanović, (Ur.), Zbornik radova X međunarodnog naučnog skupa „*Specijalna edukacija i rehabilitacija danas*" (str. 187-193), 25-26.10., Beograd: Univerzitet u Beogradu, Fakultet za specijalnu edukaciju i rehabilitaciju.
8. Arsenic, I., Simic, N. J., Lazic, M. P., Sehovic, I., & Drljan, B. (2019). Characteristics of Speech and Voice as Predictors of the Quality of Communication in Adults with Hypokinetic Dysarthria. *Serbian Journal of Experimental and Clinical Research*, *1* (ahead-of-print).
9. Buder, E. H. (2000). Acoustic analysis of voice quality: A tabulation of algorithms 1902–1990. *Voice quality measurement*, 119-244.
10. Caballero-Morales, S. O. (2013). Estimation of phoneme-specific HMM topologies for the automatic recognition of dysarthric speech. *Computational and mathematical methods in medicine*, *2013.*
11. Carrillo, L., & Ortiz, K. Z. (2007). Vocal analysis (auditory-perceptual and acoustic) in dysarthrias. *Pró-Fono Revista de Atualização Científica*, *19*(4), 381-386.
12. Clark, H. M., Duffy, J. R., Whitwell, J. L., Ahlskog, J. E., Sorenson, E. J., & Josephs, K. A. (2014). Clinical and imaging characterization of progressive spastic dysarthria. *European journal of neurology*, *21*(3), 368-376.
13. Darley, F. L., Aronson, A. E., & Brown, J. R. (1969a). Differential diagnostic patterns of dysarthria. *Journal of Speech, Language, and Hearing Research*, *12*(2), 246-269.
14. Deliyski, D., & Gress, C. (1998, November). Intersystem reliability of MDVP for Windows 95/98 and DOS. In *Annual Convention of American Speech-Language-Hearing Association, San Antonio, Texas*.
15. Dogan, M., Midi, I., Yazıcı, M. A., Kocak, I., Günal, D., & Sehitoglu, M. A. (2007). Objective and subjective evaluation of voice quality in multiple sclerosis. *Journal of Voice*, *21*(6), 735-740.
16. Duffy, J. R. (2005). Motor Speech Disorders: Substrates. *Differential Diagnosis, and Management*, *3*.
17. Fougeron, C., & Audibert, N. (2011). Testing Various Metrics for the Description of Vowel Distortion in Dysarthria. In *ICPhS* (pp. 687-690).
18. Giri, M. P., & Rayavarapu, N. (2018). Assessment on impact of various types of dysarthria on acoustic parameters of speech. *International Journal of Speech Technology*, *21*(3), 705-714.
19. Griffiths, C., & Bough Jr, I. D. (1989). Neurologic diseases and their effect on voice. *Journal of Voice*, *3*(2), 148-156.

20. Hasegawa-Johnson, M., Gunderson, J., Perlman, A., & Huang, T. (2006, May). HMM-based and SVM-based recognition of the speech of talkers with spastic dysarthria. In *Acoustics, Speech and Signal Processing, 2006. ICASSP 2006 Proceedings. 2006 IEEE International Conference on* (Vol. 3, pp. III-III). IEEE.
21. Heman-Ackah, Y. D., Michael, D. D., Baroody, M. M., Ostrowski, R., Hillenbrand, J., Heuer, R. J., ... & Sataloff, R. T. (2003). Cepstral peak prominence: a more reliable measure of dysphonia. *Annals of Otology, Rhinology & Laryngology*, *112*(4), 324-333.
22. Hillenbrand, J., Getty, L. A., Clark, M. J., & Wheeler, K. (1995). Acoustic characteristics of American English vowels. *The Journal of the Acoustical society of America*, *97*(5), 3099-3111.
23. Horwitz-Martin, R. L., Quatieri, T. F., Lammert, A. C., Williamson, J. R., Yunusova, Y., Godoy, E., ... & Green, J. R. (2016). Relation of Automatically Extracted Formant Trajectories with Intelligibility Loss and Speaking Rate Decline in Amyotrophic Lateral Sclerosis. In *INTERSPEECH* (pp. 1205-1209).
24. Jovanović Simić, N., Arsenić, I., Drljan, B., & Milovanović, T. (2019). Kvalitet komunikacije osoba sa spastičnom dizartrijom. U Žunić Pavlović, B., Grbović, A. & Radovanović, V. (Ur.), Zbornik radova X međunarodnog naučnog skupa „*Specijalna edukacija i rehabilitacija danas*“ (str. 181-186), 25-26.10., Beograd: Univerzitet u Beogradu, Fakultet za specijalnu edukaciju i rehabilitaciju.
25. Kain, A., Niu, X., Hosom, J. P., Miao, Q., & Santen, J. P. V. (2004). Formant re-synthesis of dysarthric speech. In *Fifth ISCA Workshop on Speech Synthesis*.
26. Kent, R. D., Duffy, J. R., Slama, A., Kent, J. F., & Clift, A. (2001). Clinicoanatomic studies in dysarthria: review, critique, and directions for research. *Journal of speech, language, and hearing research*, *44*(3), 535-551.
27. Kent, R. D., & Kim, Y. J. (2003). Toward an acoustic typology of motor speech disorders. *Clinical linguistics & phonetics*, *17*(6), 427-445.
28. Kent, R. D., Vorperian, H. K., & Duffy, J. R. (1999). Reliability of the Multi-Dimensional Voice Program for the analysis of voice samples of subjects with dysarthria. *American journal of speech-language pathology*, *8*(2), 129-136.
29. Kim, Y., Kent, R. D., & Weismer, G. (2011). An acoustic study of the relationships among neurologic disease, dysarthria type, and severity of dysarthria. *Journal of Speech, Language, and Hearing Research ,54*(2), 417-429.
30. Kim, Y., Weismer, G., Kent, R. D., & Duffy, J. R. (2009). Statistical models of F2 slope in relation to severity of dysarthria. *Folia Phoniatrica et Logopaedica*, *61*(6), 329-335.
31. Kreiman, J., & Gerratt, B. R. (2005). Perception of aperiodicity in pathological voice. *The Journal of the Acoustical Society of America*, *117*(4), 2201-2211.
32. Marchant, J., Mcauliffe, M. J., & Huckabee, M. L. (2008). Treatment of articulatory impairment in a child with spastic dysarthria associated with cerebral palsy. *Developmental Neurorehabilitation*, *11*(1), 81–90.
33. Maryn, Y., Roy, N., De Bodt, M., Van Cauwenberge, P., & Corthals, P. (2009). Acoustic measurement of overall voice quality: a meta-analysis. *The Journal of the Acoustical Society of America*, *126*(5), 2619-2634.
34. Mori, H., Kobayashi, Y., Kasuya, H., Hirose, H., & Kobayashi, N. (2004). F0 and formant frequency distribution of dysarthric speech-A comparative study. In *Eighth International Conference on Spoken Language Processing*.
35. Murdoch, B. E. (2014). Acquired dysarthria. In L. Cummings (Ed.), *The Cambridge handbook of communication disorders*. Cambridge: Cambridge University Press, 185-211.
36. Murdoch, B. E., Ward, E. C., & Theodoros, D. G. (2008). Spastic dysarthria. In M. McNeil (ed.), *Clinical management of sensorimotor speech disorders*, second edition. New York: Thieme Medical Publishers, 187-203.

37. Paja, M. S., & Falk, T. H. (2012). Automated dysarthria severity classification for improved objective intelligibility assessment of spastic dysarthric speech. In *Thirteenth Annual Conference of the International Speech Communication Association*.
38. Sapir, S., Ramig, L. O., Spielman, J. L., & Fox, C. (2010). Formant centralization ratio: A proposal for a new acoustic measure of dysarthric speech. *Journal of speech, language, and hearing research*.
39. Sovilj-Nikić, S. (2014). Razvoj matematičkog modela trajanja glasova u automatskoj sintezi govora na srpskom jeziku. *Doktorska disertacija*
40. Skodda, S., Grönheit, W., & Schlegel, U. (2012). Impairment of vowel articulation as a possible marker of disease progression in Parkinson's disease. *PloS one*, *7*(2), e32132.
41. Šešum, M. (2013). Komparativna analiza formantnih struktura glasova sestara i glasova monozigotnih bliznakinja. *Beogradska defektološka škola*, *19*(3), 515-527.
42. Teixeira, J. P., & Fernandes, P. O. (2014). Jitter, Shimer and HNR classification within gender, tones and vowels in healthy voices. *Procedia technology*, *16*, 1228-1237.
43. Teixeira, J. P., Ferreira, D., & Carneiro, S. M. (2011). Análise acústica vocal-determinação do Jitter e Shimer para diagnóstico de patalogias da fala. In *6º Congresso Luso-Moçambicano de Engenharia, 3º Congresso de Engenharia de Moçambique* (No. 6º). INEGI.
44. Teixeira, J. P., & Gonçalves, A. (2014). Accuracy of jitter and Shimer measurements. *Procedia Technology*, *16*, 1190-1199.
45. Toshniwal, S. S., & Joshi, N. A. (2010). Residual speech impairment in patients with traumatic brain injury. *Indian Journal of Neurotrauma*, *7*(01), 61-66.
46. Turner, G. S., & Tjaden, K. (2000). Acoustic differences between content and function words in amyotrophic lateral sclerosis. *Journal of Speech, Language, and Hearing Research*, *43*(3), 769-781.
47. Vizza, P., Mirarchi, D., Tradigo, G., Redavide, M., Bossio, R. B., & Veltri, P. (2017). Vocal signal analysis in patients affected by Multiple Sclerosis. *Procedia Computer Science*, *108*, 1205-1214.
48. Weismer, G., Jeng, J. Y., Laures, J. S., Kent, R. D., & Kent, J. F. (2001). Acoustic and intelligibility characteristics of sentence production in neurogenic speech disorders. *Folia Phoniatrica et Logopaedica*, *53*(1), 1-18.
49. Weismer, G., Martin, R., Kent, R. D., & Kent, J. F. (1992). Formant trajectory characteristics of males with amyotrophic lateral sclerosis. *The Journal of the Acoustical Society of America*, *91*(2), 1085-1098.
50. Ziegler, W., & von Cramon, D. (1986). Spastic dysarthria after acquired brain injury: An acoustic study. *International Journal of Language & Communication Disorders*, *21*(2), 173-187.