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THE ACOUSTIC CHARACTERISTICS OF VOICE AND SPEECH IN ADULTS WITH ATAXIC DYSARTHRIA

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Abstract

The aim of this study was to determine the acoustic characteristics of voice and speech in adults with ataxic dysarthria, and to examine the extent to which they differ from those of typical speakers. The sample consisted of 30 patients with ataxic dysarthria, ages 21 through 82 (M = 56.07). Using the computer programme for multidimensional voice analysis (MDVP), the individual values of 10 acoustic voice parameters were determined for each sex. Additionally, the programme provided the frequency values of the first two formants for all five vowels of the Serbian language, based on the participants' reading of the Balanced Text. The results of the analysis showed statistically significant differences in the values of the acoustic parameters between the participants with ataxic dysarthria and the reference values valid for typical speakers, which were generated by the MDVP. These differences were observed in parameters indicating voice frequency variability (F0, Fhi, Flo, STD, Jitt, vF0), voice intensity variability (Shim and vAm), and the presence of voice interruptions (DVB) and voiceless periods (DUV). Furthermore, a statistically significant difference was found between participants with ataxic dysarthria and typical speakers in the second formant (F2) of the vowels /E/ ($p < 0.01$), /I/ ($p < 0.01$), and /U/ ($p < 0.05$). The significant deviations from the norms applicable to typical speakers indicate the substantial changes present in the voice and speech of individuals with ataxic dysarthria.

Key words: acoustic characteristics, ataxic dysarthria, voice, speech.

АКУСТИЧКЕ КАРАКТЕРИСТИКЕ ГЛАСА И ГОВОРА ОДРАСЛИХ ОСОБА СА АТАКСИЧНОМ ДИЗАРТРИЈОМ

Апстракт

Циљ овог истраживања је био да се утврде акустичке карактеристике гласа и говора испитаника са атаксичном дизартријом и да се испита у којој мери се оне

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разликују од карактеристика типичних говорника. Узорак је чинило 30 пацијената са атаксичном дизартријом, узраста од 21 до 82 године (AC=56.07). Применом компјутерског програма за мултидимензионалну анализу гласа (MDVP) утврђене су вредности 10 акустичких параметара гласа за сваки пол појединачно. Истим програмом, на основу читања Балансираног текста, добијене су фреквенцијске вредности прва два форманта свих пет вокала српског језика. Резултати анализе су показали статистички значајне разлике у вредностима акустичких параметара између испитаника са атаксичном дизартријом и референтних вредности које важе за типичне говорнике, а које је генерисао MDVP. Разлике су утврђене на параметрима који указују на варијабилност фреквенције гласа (F0, Fhi, Flo, STD, Jitt, vF0), варијабилност интензитета гласа (Shim и vAm), и на присуство прекида у гласу (DVB) и перода без гласа (DUV). Такође, статистички значајна разлика између испитаника са атаксичном дизартријом и типичних говорника постојала је на другом форманту (F2) вокала /Е/ ($p<0.01$), вокала /И/ ($p<0.01$) и вокала /У/ ($p<0.05$). Значајна одступања од норми које важе за типичне говорнике указују на озбиљне промене које су присутне у гласу и говору особа са атаксичном дизартријом.

Кључне речи: акустичке карактеристике, атаксична дизартрија, глас, говор.

INTRODUCTION

Ataxia is a neurological condition characterised by deficits in motor coordination that affect various aspects of movement, including limb and eye movements, walking, speaking, and swallowing (Sidtis, Ahn, Gomez, & Sidtis, 2011). The abnormalities in muscle strength and movement control associated with ataxia, such as intentional and postural tremors and coordination disorders, also affect the muscles of the vocal tract, leading to speech disorders known as ataxic dysarthria (Mariotti, Fancellu, & Di Donato, 2005). The development of ataxic dysarthria is typically a result of cerebellar damage caused by conditions like strokes, tumours, inflammatory diseases (cerebellitis), and sporadic cerebellar degeneration, or is a manifestation of Friedrich's ataxia. The damage to the cerebellum disrupts the coordination and precision of movements in the muscles involved in speech production, particularly the articulators, leading to non-rhythmic repetitive movements, inadequate control, weakness, and slow movements with reduced muscle tone (hypotonia).

People with ataxic dysarthria exhibit distinct speech characteristics, including the inaccurate articulation of consonants and distortion of vowels. Their speech is often marked by monotony, prolonged speech intervals, stereotypical intonation patterns, and a uniform accent with expression limited to short phrases. Voice quality is also affected, typically presenting as hoarseness, tension, and a muffled voice quality (Schalling, Hammarberg, & Hartelius, 2007). Previous studies examining the acoustic analysis of voice and speech in individuals with ataxic dysarthria have identified several abnormalities. These include disruptions in speech rhythm and prosody (Liss, Spitzer, Caviness, & Adler, 2002), an increased number of inappropriate speech pauses (Rosen, Kent, & Duffy, 2003), 'scanning' speech and volatile voice modulation (Ogawa, Yoshihashi, Suzuki, Kamei, & Mizutani, 2010), inadequate syllable stress patterns, and abnormal values of *shimmer* and *jitter* (parameters measuring amplitude and voice frequency perturbations) during continuous vowel phonation (Kent et al., 2000). *Shimmer* and *jitter* are important indicators of speech intelligibility (Teixeira & Gonçalves, 2014). In addition, 'scanning' speech in ataxic dysarthria refers to the occurrence of slow speech with interrupted pauses between syllables or words. Some individuals with ataxic dysarthria also exhibit the shortening of the initial portion of vowels in their speech. The assessment of spontaneous speech and reading tasks has revealed longer pauses between syllables, prolonged syllables, and significant pauses between words (White, 2012).

PET scan studies showed reduced activity in specific brain areas associated with speech tasks, indicating a decrease in blood flow in the cerebellar hemispheres of patients with ataxic dysarthria (Sidtis, Stroghter, Naoum, Rottenberg, & Gomez, 2010). The authors emphasise that the decrease in blood flow in these individuals leads to changes in the duration of syllable pronunciation, which is one of the characteristics of ataxic dysarthria – syllable timing shifts in the direction of equal syllable duration. In contrast, in typical speakers, there is an increase in blood flow in the cerebellum during syllable repetition tasks.

Ataxic dysarthria is commonly characterised by contradictory speech patterns, as supported by literature (Hartelius, Runmarker, Andersen, & Nord, 2000). It is characterised by a combination of inadequate articulation, marked by imprecise and irregular movements, as well as prosodic outbursts. Furthermore, individuals with ataxic dysarthria may exhibit phonatory and prosodic insufficiency. The presence of these contradictory speech characteristics can be attributed to damage to various subsystems that contribute to the development of ataxic dysarthria (Spencer & Dawson, 2019). A study conducted in the 1980s by Joanette and Dudley (1980) investigated 22 patients with Friedrich's ataxia and identified two patterns of speech errors. The first pattern was associated with a general dysarthric factor characterised by imprecise articulation and prolonged phonemes. The second pattern was related to the phonatory stenosis factor, which involved hoarseness in the voice, pitch interruptions, and pitch level irregularities. Ataxic dysarthria is described as being characterised by both instability manifested through excessive variations in poorly modulated volume and pitch and inflexibility in speech, indicated by the abnormal invariance of speech expression with equal emphasis on each syllable (Hartelius et al., 2000; Spencer & France, 2016). It has been observed that individuals with ataxic dysarthria can exhibit both patterns of speech production simultaneously, which is referred to as mixed manifestation. A study conducted by Spencer and France (2016) on 10 patients with ataxic dysarthria of different etiologies found that five participants demonstrated an unstable pattern in speech production, one exhibited inflexibility, and four displayed a mixed type of speech production. In a more recent study by Spencer and Dawson (2019), which focused on eight participants with ataxic dysarthria caused by hereditary ataxia, five participants showed unstable speech production, two participants exhibited inflexibility, and one subject displayed a mixed pattern of both inflexibility and instability. Based on these findings, it can be concluded that individuals with ataxic dysarthria predominantly exhibit instability in speech, characterised by abnormal articulation, a variable voice volume and pitch, and irregular breathing. Additionally, a mixed pattern of speech difficulties is commonly observed, while inflexibility is less frequent.

Experts can identify voice and speech deficits through perceptual analysis. This method of assessment is essential and highly important, particularly for people with dysarthria, in whom intelligibility of speech production can be significantly impaired. Unsuccessful communication arises when participants encounter difficulties in adequately encoding or decoding messages (Isaković & Kovačević, 2015). However, as a supplement to perceptual assessment, which is a subjective method, the acoustic analysis of voice and speech is becoming more popular as a method for obtaining objective, quantitative data. Computerised devices enable the obtaining of numerical and graphical representations that illustrate the differences in the values of the acoustic parameters of the voices between participants with ataxic dysarthria and typical speakers. The values obtained by acoustic speech analysis may indicate abnormalities in pitch and volume, the presence of noise and tremor in the voice, and the presence of inadequate pauses in speech, subharmonics, and periods without voice. Additionally, these computerised devices that analyse the recorded voice sample provide a spectrographic representation of the position of voice formants. The proper shape, position, and interrelationships of these formants allow for individual voice recognition, which can also determine the overall intelligibility of speech production. Acoustic voice and speech analysis programmes also facilitate the monitoring of a patient's progress during treatment by tracking changes in the values of acoustic parameters over a specific period of time. Additionally, these programmes include tasks that might help patients in enhancing their voice quality and speech intelligibility.

Only a few studies have examined the acoustic characteristics of the voice and speech of individuals with ataxic dysarthria. These studies were conducted on samples of participants who are part of a larger context in which dysarthria is generally viewed as a motor speech disorder, without any emphasis placed on the specific aspects related to a concrete type of dysarthria. Perceptual analysis was previously used to determine the voice and speech characteristics of people with dysarthria (Chenery, Ingram, & Murdoch, 1990; Ozsancak, Parais, & Auzou, 2002; Zyski &

Weisiger, 1987). However, due to advances in computer technology, it is now possible to obtain quantitative data on these people's voice and speech characteristics, as well as on deviations from norms. Additionally, it is important to note that certain characteristics of speech in individuals with ataxic dysarthria may not be readily detected through perceptual assessment alone, so the use of a computer programme in the analysis of voice and speech as an additional method is always considered desirable. Perceptual analysis is not always an objective means of assessing voice changes in individuals with dysarthria because it cannot detect all the parameters that can affect speech intelligibility. On the other hand, the use of computer programmes in voice and speech analysis enables the precise measurement of all acoustic parameters, contributing to the objectivity of the assessment. Computer analysis has been used in previous studies with individuals with ataxic dysarthria, but it was mostly limited to the acoustic analysis of a smaller sample of participants and was devoid of spectral speech analysis (Kent et al., 2000). Additionally, previous studies investigating the acoustic parameters in individuals with ataxic dysarthria primarily focused on parameters related to the fundamental frequency of voice, while other aspects such as voice intensity, voice breaks, and voiceless intervals were not examined (Ackermann & Ziegler, 1994). Furthermore, some studies only examined a limited set of voice acoustic parameters, such as fundamental frequency, jitter and shimmer (Gómez-Coello et al., 2017; White, 2012). Finally, it should be noted that the majority of research on the spectral analysis of speech samples in individuals with dysarthria originates in English-speaking regions, and to our knowledge, no similar research on Serbian speakers has been conducted. Given the articulatory specificities of the Serbian language, spectral analysis of Serbian speakers with dysarthria can significantly contribute to modifying and adapting the rehabilitation strategies used for these individuals in our region.

Based on the findings of previous studies, the objective of this study was to use acoustic analysis to measure the values of specific acoustic voice parameters in people with ataxic dysarthria. Also, using the spectral analysis of speech, we aimed to determine the frequency values of the first two formants of vowels in Serbian speakers with ataxic dysarthria. The goal was to investigate the degree to which these values differ from the norms observed in typical speakers.

METHODS

Sample

The study included 30 patients with ataxic dysarthria ages 21 through 82 (AS = 56.07). Among the total number of participants, 22 were male (73.3%) and 8 were female (26.7%). The participants' native language was Serbian, and none of them had a professional background in vocals. Ataxia in all participants was of cerebrovascular origin. Additionally, they did not have any other associated disorders, or a history of illness that could impact speech and voice characteristics.

Instruments and Procedure

The research was conducted in Belgrade and included participants who were patients at the "St. Sava" Special Hospital for Cerebrovascular Diseases and the "Dr. Miroslav Zotović" Clinic for Rehabilitation. The MDVP (Multi-Dimensional Voice Program) computer programme, specifically the model 4300 from the Kay Elemetrics Corporation, was used to perform the acoustic analysis of the participants' voice and speech. To extract the values of the voices' acoustic parameters, a sample of continuous phonation of the vowel /a/ was obtained, with a duration of 3 to 5 seconds. Additionally, spectral analysis was performed on speech samples obtained by asking the participants to read the Balanced Text (Šešum, 2013). The Balanced Text is a text created specifically for the forensic analysis of voice and speech. Over the years, its unique features have made it a valuable resource for research purposes (Šešum, 2013, 2020, 2021). The term 'text balance' refers to the natural distribution of syllable frequencies within meaningful units of the Serbian language. The text is carefully constructed to include all Serbian language sounds in initial and medial articulatory positions, as well as the 14 most frequently occurring sounds in the final position. Moreover, the text maintains semantic coherence and contains complex statements suitable for speech analysis. With a total of 7 sentences, the text is of optimal length, preventing speakers' fatigue during the analysis.

Voice and speech samples were recorded individually for each participant in a soundproof room. The participants were instructed to use optimal volume and pitch during the recordings. The pattern of continuous vowel /a/ phonation was selected because it is considered to yield a stable performance, enabling the extraction of specific acoustic parameters of the voice. Given that there are sex-related differences in certain acoustic parameters, the acoustic analysis was conducted separately for men and women. However, the determination of vowel formant values for the specific language was based on the pronunciation of those vowels in spontaneous speech, and separate analyses for male and female participants was not necessary, as formant values are not dependent on the pitch of the fundamental laryngeal tone and are consistent across genders. In cases where participants were unable to read the given text, they repeated it after the researcher. The voice and speech samples were analysed at the "Zvezdara" Clinical Hospital Centre in Belgrade

Using the voice analysis programme (MDVP), we obtained the values for the 10 acoustic parameters identified in previous studies as important indicators of speech abnormalities in patients with ataxic dysarthria and other types of dysarthria. Deviations from the norms applicable to typical speakers suggest voice pathology, and potential changes in the vocal cords and other speech organs. The norms are established based on the values of acoustic parameters derived from the MDVP analysis of a sample of typical male and female speakers. The measured parameters include frequency variability indicators such as fundamental frequency (F0), highest (Fhi) and lowest (Flo) frequency values, standard deviation (STD), variation (vF0), and perturbation of fundamental frequencies (Jitt) indicating irregularities in vocal cord vibration rate. Intensity variability (amplitude) is assessed through parameters indicating amplitude perturbations (Shim) and peak-to-peak amplitude variations (vAm). Additionally, the analysis includes parameters related to voice interruptions and irregularities, represented by the degree of voice breaks (DVB) and the degree of voiceless periods (DUV). Both DVB and DUV are presented as percentages, and their reference values for typical speakers are 0, as there should be no interruptions or periods without voice during speaking and continuous phonation.

The position of the first two formants (F1 and F2) for all vowels in the Serbian language was determined using speech samples obtained from participants who read a phonetically balanced text. Formants represent areas of increased sound energy at specific frequencies. The structure of formants is influenced by the length and shape of the vocal tract, as well as the movements of the jaw, tongue, and lips (Shriberg, Kent, & Munson, 2003). While the first three formants are important for the auditory discrimination of voices, this research focused on analysing the first two formants, which carry the most energy. The third formant was not included in the analysis because, although it contributes to voice quality and clarity, its values are similar across all vowels in the Serbian language, and do not significantly affect their discrimination.

Statistical Analysis

The statistical analysis of the data involved descriptive statistics, including frequencies, percentages, arithmetic mean, and standard deviation to summarise the characteristics of the sample. To examine the differences between the sample values and the norms, a one-sample t-test was performed. The significance level was set at $p < 0.05$, indicating a statistically significant difference. The statistical software used for data processing and analysis was SPSS ver. 24 (Statistical Package for the Social Sciences) for Windows.

RESULTS

In previous studies, the most common deviations in the values of acoustic voice parameters were found in parameters related to fundamental frequency variability, such as variation, standard deviation, and perturbation of the fundamental frequency (vF0, STD, and Jitt), as well as in parameters related to voice intensity variability, such as peak-to-peak amplitude variation and amplitude perturbation (vAm and Shim) (Kent et al., 2000). These parameters, specifically Shim and Jitt, have been identified as significant indicators of acoustic voice abnormalities in individuals with ataxic dysarthria, as well as other types of dysarthria (Jannetts & Lowit, 2014; Kent et al., 2000). Furthermore, due to the presence of tremors during speech production, the F0 parameter differs between individuals with ataxic dysarthria and the control group (Gómez-Coello et al., 2017; White, 2012). Besides the mentioned parameters, the highest and lowest values of fundamental frequency (Fhi and Flo) were also determined in this study. Furthermore, considering the frequent and significant pauses in the speech of individuals with ataxic dysarthria, as well as the occurrence of 'scanning speech', it was examined whether voice interruptions and periods without voice occur during continuous phonation (DVB and DUV). Tables 1 and 2 present the values of the ten analysed acoustic parameters of the voices of 30 participants with ataxic dysarthria, separated according to gender.

Table 1. Average values of acoustic parameters of voice and differences in relation to norms – men

		N	MDVP norms	Ataxic dysarthria		T	p
			M	M	SD		
F0	(Hz)	22	145.233	144.987	23.461	-0.049	0.961
Fhi	(Hz)	22	150.080	249.327	153.594	3.031	***0.006***
Flo	(Hz)	22	140.418	109.988	25.944	-5.501	***0.000***
STD	(Hz)	22	1.349	18.378	27.137	2.943	***0.008***
Jitt	(%)	22	0.589	2.691	3.085	3.195	***0.004***
vF0	(%)	22	0.939	10.890	14.744	3.166	***0.005***
Shim	(%)	22	2.523	10.314	6.429	5.685	***0.000***
vAm	(%)	22	7.712	27.022	9.413	9.622	***0.000***
DVB	(%)	22	0.200	1.972	3.561	2.335	***0.030***
DUV	(%)	22	0.200	19.139	28.555	3.111	***0.005***

F0 – average fundamental frequency, Fhi – highest fundamental frequency, Flo – lowest fundamental frequency,
STD – standard deviation of F0, Jitt – absolute Jitter, vF0 – fundamental frequency variation, Shim – Shimmer percent,
vAm – peak-to-peak amplitude variation, DVB – degree of voice brakes, DUV – degree od voiceless periods

According to Table 1, nine of the ten analysed acoustic parameters of voice demonstrate statistically significant deviations from the reference values for typical speakers. The only parameter that does not show a statistically significant difference is the fundamental voice frequency (F0), which is slightly lower than the average values for male speakers.

Table 2. Average values of acoustic parameters of voice and differences in relation to norms – women

		N	MDVP norms	Ataxic dysarthria		T	p
			M	M	SD		
F0	(Hz)	8	243.973	243.973	26.162	-8.046	***0.000***
Fhi	(Hz)	8	252.724	252.724	29.134	-5.753	***0.001***
Flo	(Hz)	8	234.861	234.861	47.589	-6.577	***0.000***
STD	(Hz)	8	2.722	2.722	20.952	2.159	0.068
Jitt	(%)	8	0.633	0.633	1.404	2.868	***0.024***
vF0	(%)	8	1.149	1.149	11.203	2.464	***0.043***
Shim	(%)	8	1.997	1.997	4.800	3.871	***0.006***
vAm	(%)	8	10.743	10.743	27.157	2.559	***0.038***
DVB	(%)	8	0.200	0.200	27.311	1.539	0.168
DUV	(%)	8	0.200	0.200	22.023	2.578	***0.037***

F0 – average fundamental frequency, Fhi – highest fundamental frequency,
Flo – lowest fundamental frequency,
STD – standard deviation of F0, Jitt – absolute Jitter,
vF0 – fundamental frequency variation, Shim – Shimmer percent,
vAm – peak-to-peak amplitude variation, DVB – degree of voice brakes,
DUV – degree od voiceless periods

Table 2 indicates that eight out of the ten analysed acoustic parameters of the voices of women with ataxic dysarthria demonstrate statistically significant differences compared to the average values generated by the programme for typical female speakers. Parameters STD and DVB do not show statistically significant differences, but have higher values compared to the norms. The values of parameters F0, Fhi, and Flo are significantly lower in relation to the values representing the norms for women without a voice disorder. The placements of the first and second formants (F1 and F2) of all Serbian vowels (Table 3) were determined by analysing the speech samples collected by asking the 30 participants with ataxic dysarthria to read the Balanced Text.

Table 3. Average values of vowel formants and differences in relation to norms – entire sample

Vowel		N	Min	Max	M	SD	T	p
A	F1	30	481.000	1345.000	644.133	164.615	1.468	0.153
	F2	30	508.000	1465.000	1185.033	194.861	0.423	0.676
E	F1	30	358.000	1644.000	540.467	217.934	1.017	0.318
	F2	30	298.000	1913.000	1479.333	337.621	-3.904	***0.001***
I	F1	30	179.000	1943.000	365.500	316.658	1.133	0.267
	F2	30	627.000	2451.000	1893.467	390.715	-2.895	***0.007***
O	F1	30	388.000	1106.000	548.367	142.777	0.359	0.722
	F2	30	328.000	1173.000	967.600	150.377	-0.816	0.421
U	F1	30	269.000	956.000	373.600	127.459	-0.275	0.785
	F2	28	627.000	1524.000	896.429	240.680	2.120	***0.043***

F1 – first formant, F2 – second formant

Table 3 illustrates statistically significant differences in the second formant (F2) of the vowels /E/ ($p < 0.01$), /I/ ($p < 0.01$), and /U/ ($p < 0.05$) between participants with ataxic dysarthria and typical speakers. However, the spectral analysis of the vowel /U/ could not be conducted for two participants. The position of the second formant (F2) in the vowels /E/ and /I/ is significantly lower compared to the norms. Conversely, the average value of F2 in the vowel /U/ among participants with ataxic dysarthria was significantly higher. The average values of the first formant (F1) and second formant (F2) for the vowels /A/ and /O/ fell within the norms.

DISCUSSION

The results of the acoustic analysis of voice revealed differences in the values of the analysed acoustic parameters of voice between male and female participants with ataxic dysarthria, and typical speakers. In male participants, nine out of the ten analysed parameters showed a statistically significant difference, on average, from the reference values for typical speakers. The only parameter that did not show a statistically significant difference was the fundamental voice frequency (F0), which was slightly lower than the average value for typical male speakers. This lower average value of F0 in male participants was related to the lower value of the parameter Flo. All other parameters had higher values compared to the norms for typical male speakers. In female participants, the parameters representing the standard deviation of the fundamental frequency (STD) and the degree of voice breaks in percentage (DVB) did not differ statistically from the norms, but had higher values than the norms. The values of the fundamental frequency of the voice (F0, Fhi, Flo) were statistically significantly lower compared to the values representing the norms for females without a voice disorder. All other acoustic parameters had statistically significantly higher values than the norms. These findings indicate significant deviations in the acoustic parameters of the voices of the participants with ataxic dysarthria, both in men and women, compared to typical speakers.

The fundamental voice frequency (F0) represents the number of vocal cord vibrations per unit of time (seconds) and varies between men, women, and even within individuals across different utterances (Langarani & Van Santen, 2014). In our research, the average F0 values were slightly lower in men, and statistically significantly lower in women compared to the norms. In women, this finding indicates impaired voice quality due to vocal cord dysfunction. Additionally, most of the other analysed acoustic parameters had higher values, with the majority showing a statistically significant difference from the norms. Elevated values of the Jitt parameter indicate the presence of voice perturbations and poorer voice quality (Deliyski & Gress, 1998). The presence of any type of voice variation leads to an increase in the vF0 parameter, as observed in our study. The Shim parameter, which indicates phonatory stability, increases in value due to vocal cord lesions, and is associated with breathiness and noise in the voice. In individuals with various types of dysarthria, including ataxic dysarthria, abnormally high values of the Jitt and Shim parameters have been noted, indicating pitch and volume perturbations, which is consistent with the findings of this research (Teixeira & Fernandes, 2014). The obtained elevated values of the DVB and DUV parameters in both male and female participants with ataxic dysarthria indicate the presence of interruptions and periods without voice during tasks requiring continuous phonation. These parameters are expressed as a percentage, and values close to 0 (zero) are expected in typical speakers, as continuous phonation should not have interruptions or voiceless periods. It is noteworthy that the interpretation of DVB and DUV values in individuals with dysarthria is scarce in available literature, despite the presence of speech and voice interruptions, as well as periods without phonation due to dysfunctions in respiratory, phonatory, and articulatory mechanisms. Overall, the findings of this research highlight the deviations in acoustic parameters, including F0, Jitt, Shim, DVB, and DUV, in individuals with ataxic dysarthria, indicating voice abnormalities and disruptions in the continuous phonation of speech. This fact is surprising, especially because, for example, the speech of individuals with hypokinetic and spastic dysarthria is characterised by voice breaks (Duffy, 2013). The speech of individuals with ataxic dysarthria is characterised by an inadequate rhythm with interruptions, which reduces its intelligibility and leads to the emergence of an unnatural quality of speech. This phenomenon is referred to as ‘scanning speech’, and perceptually, it is observed as speech production segmented into syllables (Henrich, Lowit, Schalling, & Mennen, 2006). The average values of these two parameters in a sample of 30 participants with ataxic dysarthria indicate the presence of impaired speech flow and prosodic characteristics.

A review of the available literature reveals that other researchers have obtained similar results. In the Kent et al. (2000) study, significant abnormalities were also observed in participants with ataxic dysarthria regarding the average values of parameters such as vF0 and STD, while Jitt, vAm, and Shim showed a high degree of abnormality. The elevated values of the Jitt and Shim parameters in individuals with ataxic dysarthria can be attributed to impaired respiration and vocal cord function, which are common features in various types of dysarthria (White, 2012). These changes in parameter values are considered to be the fundamental characteristics of speech in individuals with ataxic dysarthria (Kent et al., 2000). This was additionally supported by a recent study conducted by Gómez-Coello et al. (2017), which also reported significantly higher values for the Shim and Jitt parameters, and lower values for F0 compared to the norms, which aligns with the findings of our research. Furthermore, other studies analysing the acoustic characteristics of the voices in individuals with ataxic dysarthria, such as those by Ackermann and Ziegler (1994) and Kain et al. (2004), have consistently found statistically significantly higher average values for the Jitt parameter.

In individuals with ataxic dysarthria, the most prominent deficits are observed in the domains of articulation and prosody. The articulation of both consonants and vowels is disrupted due to the slow and inaccurate movements of the oral and pharyngeal muscles. Tongue movements, which are necessary for the clear articulation of vowels and consonants, are particularly affected in individuals with ataxic dysarthria, as they become limited and imprecise, with rapid and alternating movements of the tongue to the side and upwards. These abnormal tongue movements in patients with ataxic dysarthria contribute to the difficulties in producing precise and intelligible speech. Additionally, individuals with ataxic dysarthria experience difficulty in performing slow alternating lip movements (Enderby, 1986). As a result of these impairments, changes occur in the positioning of vowel formants on the frequency scale in individuals with ataxic dysarthria. The position of the tongue and lips play a crucial role in determining the positioning of the formants. Specifically, the height of the tongue during vowel articulation influences the position of F1, while the protrusion or retraction of the tongue affects the value of F2 (Nieman, 2018). Similarly, the position and shape of the lips when producing vowels also contribute to the positioning of both F1 and F2 (Kent, Weismer, Kent, Vorperian, & Duffy, 1999).

Inadequate vowel articulation is commonly observed in various types of dysarthria, including ataxic dysarthria. Spectral analysis is a useful tool for detecting deviations in the expected frequencies of the formants, as well as their centralisation. It can also reveal changes in formant spacing, shallower slopes, and variability in vowel transitions (Caballero-Morales, 2013). Moreover, spectral analysis can provide insights into the quality of the voice. Individuals with ataxic dysarthria often have a throaty voice quality, characterised by a rough or strained vocal quality (Carmichael, 2014).

In the present study, the results of the spectral analysis of the speech of 30 participants with ataxic dysarthria revealed statistically significant differences in the second formant (F2) among different vowels. The F2 values in the vowels /E/, /I/, and /U/ showed significant differences between participants with ataxic dysarthria and typical speakers ($p < 0.01$ for /E/ and /I/, $p < 0.05$ for /U/). Specifically, the position of the second formant (F2) in the vowels /E/ and /I/ was found to be significantly lower compared to the norms. The average F2 value in the vowel /E/ for participants with ataxic dysarthria was M = 1479.333 Hz, while it falls within the range between 1720 and 2000 Hz in typical speakers. In the vowel /I/, the average F2 value was M = 1893.467 Hz, whereas it ranges between 2100 and 2500 Hz for typical speakers. Interestingly, the average F2 value in the vowel /U/ for participants with ataxic dysarthria was statistically significantly higher (M = 896.429 Hz), compared to the F2 range observed in typical speakers, which is between 650 and 800 Hz. Notably, the average values of F1 and F2 for the vowels /A/ and /O/ in the participants with ataxic dysarthria were within the expected norms.

The reduction of F2 in vowels has been identified as a valid sign of impaired speech intelligibility in individuals with dysarthria, and aids in the classification of ataxic dysarthria (Lansford & Liss, 2014). Furthermore, the results of the study by Lansford and Liss (2014) indicate a correlation between the phenomenon of centralisation and poor speech intelligibility. The reduction in the slope of the second formant in vowels has been observed in this study, as well as in the study conducted by other authors (Kent et al., 1999; Kim et al., 2009). Kim et al. (2009), on the other hand, investigated the possibilities of F2 slope as a quantitative metric of the severity of speech-motor control deficits in dysarthria. Other studies have underlined the occurrence of 'formants frequency centralisation' and a reduction in the vowel space area in people with dysarthria. The formant centralisation ratio was examined by Sapir and associates (2010) as an objective measure for distinguishing dysarthric from normal speech. The authors discovered that this centralisation phenomenon arises from the irregular and reduced movements of the articulators, which result in narrower intervals between vowel formants, particularly between F1 and F2. Arsenic and colleagues (2019) determined the link between formant centralisation and communication quality in people with dysarthria.

Through the spectral analysis of the participants' speech samples, we observed statistically significant differences in the position of formants compared to the norms in our research, along with the phenomenon of vowel centralisation. The values of the second formant were found to be significantly lower in the vowels /E/ and /I/, indicating centralisation. Additionally, although not statistically significant, the average value of F1 in the vowel /I/ was higher, further confirming the centralisation phenomenon in individuals with dysarthria. Conversely, the average values of F2 in the vowel /U/ were significantly higher, suggesting the absence of formant centralisation in this particular vowel.

The Limitations of the Study

It is important to acknowledge that this study has certain limitations. First, the sample size of participants with ataxic dysarthria is small, which may limit the possibility of drawing reliable conclusions. Additionally, the significant age variation among participants could be a confounding factor, as certain acoustic voice parameters can be influenced by age-related changes (Nishio, Tanaka, & Niimi, 2011). Therefore, future research should aim to include a larger and more age-homogeneous sample of individuals with ataxic dysarthria. Furthermore, while acoustic and spectral analysis of voice and speech provide objective quantitative data on deviations in voice and speech characteristics of individuals with ataxic dysarthria compared to typical speakers, it is important to complement these findings with perceptual assessment methods. Perceptual assessment can provide a more comprehensive understanding of speech pathology and its impact on communication. Future studies should consider integrating acoustic analysis and perceptual assessment in order to obtain a more holistic view of the speech characteristics of patients with ataxic dysarthria.

In addition, it would be beneficial to explore a broader range of acoustic voice parameters, as tools like MDVP can process multiple parameters (e.g., 33 acoustic parameters). Conducting spectral analysis on all sounds in a specific language spoken by individuals with dysarthria would provide more precise information on the specificities and characteristics of their voice and speech. Moreover, comparing the results of acoustic analyses across different types of dysarthria could help identify unique parameter values and formant arrangements that may be indicative of specific types of dysarthria or related conditions.

CONCLUSION

Undisturbed communication between individuals relies on the presence of clear and intelligible speech production, without interruptions or compromised voice quality. Ataxic dysarthria, a motor speech disorder primarily caused by cerebellar damage, manifests as muscle hypotonia, slow and imprecise movements, tremors, and lack of coordination during speech articulation. This condition affects respiratory, phonatory, and articulatory mechanisms, resulting in voice quality disturbances, articulation difficulties, and prosodic deficits.

The computer program MDVP was used to analyse the acoustic voice parameters of a group of 30 participants with ataxic dysarthria, revealing statistically significant differences in the measured values. These values indicate a decrease in pitch, the presence of pitch and volume perturbations, as well as periods without voice and pauses during speech production. The significant deviations from the norms applicable to typical male and female speakers highlight the presence of a significant voice and speech pathology in individuals with ataxic dysarthria. Additionally, spectral analysis identified significant deviations in the frequency values of certain vowel formants, along with the occurrence of formant centralisation.

The results obtained during this study were compared and found to be consistent with the findings of previous studies in terms of many acoustic parameters and the frequency position of vowel formants. However, there is a scarcity of studies specifically focused on examining the acoustic characteristics of the voice and speech of individuals with ataxic dysarthria as a distinct sample, separate from other types of dysarthria. Furthermore, certain speech characteristics in individuals with ataxic dysarthria may not be easily identified through perceptual assessment alone, underscoring the importance of employing computer programmes as an additional method for voice and speech analysis. Overall, besides its diagnostic value, the acoustic analysis of voice and speech in individuals with ataxic dysarthria, as well as other types of dysarthria, can significantly contribute to determining appropriate treatment approaches. MDVP, for example, includes tasks that can facilitate treatment and assist patients in achieving optimal values for individual acoustic voice parameters.

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АКУСТИЧКЕ КАРАКТЕРИСТИКЕ ГЛАСА И ГОВОРА ОДРАСЛИХ ОСОБА СА АТАКСИЧНОМ ДИЗАРТРИЈОМ

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Резиме

Атаксична дизартрија се јавља као последица оштећења малог мозга услед ког долази до поремећаја у координацији и прецизности покрета мишића ефекторног система, нарочито артикулатора, уз хипотонију мишића. Говор особа са атаксичном дизартријом се одликује непрецизном артикулацијом консонаната и вокала, монотоношћу, пролонгирањем говорних интервала, стереотипним интонационим обрасцима, уједначеним акцентом и изражавањем у кратким фразама. Присутни су храпав, напет и пригушен глас, поремећај ритма и прозодије говора, повећан број неадекватних пауза у говору, „скандирање“ приликом вокализације и колебљива модулација гласа, неадекватан шаблон наглашавања слогова, као и абнормалне вредности акустичких параметара гласа.

Данас се све чешће спроводи акустичка анализа гласа и говора помоћу компјутеризованих уређаја, на основу које се добијају објективни, квантитативни подаци. Нумеричким и графичким приказима представљају се разлике у вредностима акустичких параметара гласа између испитаника са патологијом говора и типичних говорника. Такође, добија се спектрографски приказ положаја форманата гласова чији правилан облик, положај и међусобни однос омогућавају препознавање сваког гласа појединачно и утичу на општу разумљивост говорне продукције. Програми за акустичку анализу гласа и говора омогућавају и праћење напретка пацијента у току третмана, али и садрже задатке помоћу којих пацијенти могу да побољшају квалитет гласа и разумљивост говорне продукције.

Мали број студија се бави испитивањем акустичких карактеристика гласа и говора особа са атаксичном дизартријом. Углавном су ови испитаници део већег узорка у коме се дизартрија посматра глобално, као моторички поремећај говора, без истицања специфичности везаних за тип дизартрије. Сходно наведеном, циљ овог истраживања је био да се утврде акустичке карактеристике гласа и говора испитаника са атаксичном дизартријом и да се испита у којој мери се оне разликују од карактеристика типичних говорника. Узорак је чинило 30 пацијената са атаксичном дизартријом, оба пола и узраста од 21 до 82 године (AC=56.07). Применом компјутерског програма за мултидимензионалну анализу гласа (MDVP) утврђене су вредности 10 акустичких параметара гласа за сваки пол појединачно. Истим програмом, спектралном анализом узорка говора добијеног читањем Балансираног текста, утврђене су фреквенцијске вредности прва два форманта свих пет вокала српског језика.

Резултати анализе су показали статистички значајне разлике у вредностима аустичких параметара између испитаника са атаксичном дизартријом и референтних вредности које важе за типичне говорнике, а које је генерисао MDVP. Разлике су утврђене на параметрима који указују на варијабилност фреквенције гласа (F0, Fhi, Flo, STD, Jitt, vF0) и варијабилност интензитета гласа (Shim и vAm), као и на присуство прекида у гласу (DVB) и перода без гласа (DUV). Спектралном анализом су утврђене статистички значајне разлике између испитаника са атаксичном дизартријом и типичних говорника српског језика на другом форманту (F2) вокала /Е/ ($p<0.01$), вокала /И/ ($p<0.01$) и вокала /У/ ($p<0.05$), при чему је утврђена и централизација фреквенције форманата. Значајна одступања од норми које важе за типичне говорнике указују на перцептуално упадљиве промене које су присутне у гласу и говору особа са атаксичном дизартријом.