Assessing speech intelligibility in a group of Egyptian dysarthric patients

Mohamed Sadek Refai[b], Azza Adel Aziz[a], Dalia Mostafa Osman[a] and Shahinaz Farag El-Shafee[c]

[a]Phoniatric Unit, [b]ENT Department, Faculty of Medicine, Cairo University and [c]Hearing and Speech Institute, Cairo, Egypt

Correspondence to Dalia Mostafa Osman, Phoniatric Unit, ENT Department, Faculty of Medicine, Cairo University, Cairo, Egypt
Tel: +0106337599; fax: +(02)23642124;
e-mail: dmostafa9999@yahoo.com

Received 4 August 2011
Accepted 5 September 2011

The Egyptian Journal of Otolaryngology
2012, 28:49–55

Background
Improving speech intelligibility in dysarthric patients is considered the primary goal of therapeutic intervention.

Aim
This study aimed at examining factors affecting speech intelligibility in four Arabic-speaking dysarthric groups using perceptual and instrumental techniques in order to gain a better understanding of the important factors contributing to reduced speech clarity in these patients.

Methods and procedures
Participants included 30 male Egyptian dysarthric patients (patient group) and 30 male age-matched healthy individuals (control group). The patient group was subdivided – on the basis of the neurological examination and investigation that had been carried out previously at the Neurology Department, Kasr el Aini Hospital – into four subgroups; spastic, ataxic, flaccid, and hypokinetic (having Parkinsonism). Speech samples consisting of spontaneous speech and a standard reading passage (that the participants were asked to repeat after the assessor) were used to obtain the following variables: speech rate (number of words per minute), Speech Intelligibility Score, number of nonintelligible words per minute, dysphonia grade, percent of consonants correct, percent of vowels correct, Nasalance Score, fundamental frequency, jitter, shimmer, harmonic-to-noise ratio, duration of /a/, first and second formant frequency values for three corner vowels /a/, /i/, and /u/, voice onset time of /b/, /t/, /k/, stop gap of /t/, /t/, /d/, /d/, and duration of /s/ and /ʃ/. The study examined the differences between the healthy control group and the different dysarthric groups for each variable as well as the correlation between speech intelligibility and each variable within each dysarthric subgroup.

Outcomes and results
The Speech Intelligibility Score was the highest for flaccid dysarthria and the lowest for ataxic. Results revealed significant differences between the control group and each of the patient groups studied for all subjective measures as well as most of the instrumental measures that were included in the study. A significant positive correlation was found between speech rate and speech intelligibility in patients with ataxic and flaccid dysarthria. However, a negative correlation was found between speech rate and speech intelligibility in patients with hypokinetic dysarthria. A significant negative correlation was found between speech intelligibility and jitter, F1 and F2 of /u/, stop gap of /t/, /t/, /d/, and /d/, and /s/ duration in spastic, ataxic, and flaccid groups. In addition, a significant negative correlation was found between shimmer and speech intelligibility in the ataxic group and between Nasalance Score and speech intelligibility in the flaccid group.

Conclusion and implications
Factors contributing to reduced speech intelligibility vary from one type of dysarthria to the other.

Keywords:
Arabic-speaking adults with dysarthria, dysarthria, Egyptian patients with dysarthria, speech clarity, speech intelligibility in dysarthria

Egypt J Otolaryngol 28:49–55

1012-5574

Introduction

Speech intelligibility is an essential component of spoken language. It is the degree to which an acoustic signal is understood by the listener [1]. In the case of dysarthria, speech intelligibility can be affected by many factors including the type of dysarthria as well as the underlying pathophysiological changes [2].

In dysarthric patients, factors affecting speech intelligibility include changes in speech rate, imprecise consonants, distorted vowels, and hypernasality [3]. Evaluation of speech intelligibility in dysarthric patients has been approached in a number of ways such as auditory perceptual assessment, open-set word identification, closed-set word identification [4], articulation/phonological tests [5], and some protocols [6].

Although auditory perceptual assessment is still the most commonly used technique to assess speech in dysarthric patients, it has some limitations, one of which is that it can be difficult even for highly trained therapists to differentiate between the multiple dimensions of dysarthric speech impairment. Therefore, it is better to supplement such perceptual methods with some objective techniques [7] such as acoustic analysis [8].

Speech difficulties exhibited by dysarthric patients can be acoustically detected in the form of changes in vowel formants, secondary to restricted range of lingual movements, and changes in fricative duration [9], voice onset time (VOT), fundamental frequency, and frequency and/or amplitude perturbations [10]. Lengthened vowel duration is a fundamental property of ataxic dysarthria [9]. Prolonged VOT was also found in spastic and athetoid dysarthria. Abnormal tempo can reduce speech intelligibility in hypokinetic and ataxic dysarthria [11] because of the negative impact that abnormal speech rate can have on the full achievement of consonant articulation [12]. Other researchers have also reported dysynchrony between velar and lingual movements in athetosis leading to segmental errors. In addition, reduced tongue movement in dysarthric patients was also found to be associated with a reduction in Fl and F2 values for some vowels [13]. However, most of these researches were carried out on dysarthric patients speaking languages other than Arabic. Unfortunately, few research studies have been carried out on Arabic-speaking participants.

Aim

This study aimed at examining the factors affecting speech intelligibility in four Arabic-speaking dysarthric groups using perceptual and instrumental techniques in order to gain a better understanding of the important factors contributing to reduced speech clarity in these patients.

Patients and methods

This study examined the speech characteristics of 30 male patients with dysarthria and 30 healthy male control participants. Dysarthric patients were recruited from the Neurology Department, Kasr Al Aini Hospital. The pathological classification of the constituent groups was based on their previous neurological diagnosis. Consent to participate in the study was obtained from the patients before the onset of the study.

Participants in the control group were 35–55 years old with a mean age of 45 years. Among patients with dysarthria, there were eight patients with spastic dysarthria (diagnosed with ischemic vascular stroke by a qualified neurologist). They were 39–55 years old with a mean age of 45 years. Eight patients had ataxic dysarthria (age range 33–50 years, mean age 44 years), eight patients had flaccid dysarthria (44–55 years old, mean age of 47 years), and six patients had hypokinetic dysarthria with parkinsonism (49–58 years old, mean age 50 years).

Subjective assessment

For each participant under study, history taking and examination were carried out. Thereafter, a sample of the participants' speech was taken and audio-digitally recorded in a sound-treated room, in which he was asked to mention his name, age, describe his daily routine, and repeat a certain standard passage that had been especially designed so that it would cover all the Arabic consonants.

From the sample taken, the following were calculated: (i) speech rate (number of words per minute). (ii) Speech Intelligibility Score. Five unfamiliar listeners were asked to listen to the recorded speech samples and were asked to repeat what they had heard, which was transcribed. According to the transcription obtained, each participant was given a score. The scores obtained by the five listeners for each participant were then summed up and divided by five to obtain the average Speech Intelligibility Score for each participant. The scores were graded as follows: grade 1 = speech is completely unintelligible, grade 2 = speech is very difficult to understand, except for a few isolated words (five to 10 words), grade 3 = speech is understood by unfamiliar persons half of the time (almost 50% of the time), grade 4 = speech is intelligible with the exception of a few words or phrases (five to 10 words), grade 5 = speech is completely intelligible for all words. (iii) The number of unintelligible words were counted and divided by the duration of the sample taken (in 10 min) to obtain the number of unintelligible words per minute for each participant. (iv) Dysphonia grade was obtained using the modified GRBAS Scale (overall Grade, Roughness, Breathiness, Asthenia, Strained) [14]. (v) The number of consonants correct (out of 28) was calculated by asking each participant to repeat the 28 Arabic consonants in vowel–consonant–vowel syllabic forms with the vowel /a/. (vi) The number of vowels correct (out of eight) was obtained by asking each participant to repeat words with various constituent vowels. These were, ʕi:d, zet, xox, tu:t, baeb, ragil, bɛnt, ɔsama (عيد, زيت, خوخ, توت, باب, راجل بنت,أسامه).

Objective assessment

Objective assessment included the following: (i) nasometric studies: each participant was asked to repeat a standard oral and nasal passage. Data were then analyzed and the mean Nasalance Score was calculated by obtaining the ratio of nasal-to-nasal plus oral acoustic energy multiplied by 100. (ii) Acoustic analysis was carried out by asking each participant to produce the vowel /a/ in a sound-treated room to obtain the average values for fundamental frequency (F0), jitter, shimmer, harmonic-to-noise (*H*/*N*) ratio, average energy, and average duration for /a/. (iii) Spectrographic analysis was carried out to determine VOT for /b/, /t/, and /k/ by asking each participant to produce these sounds in vowel–consonant–vowel syllabic forms with the vowel /a/. These stops were chosen to study changes in VOT of stops with different places of articulation: the bilabial /b/, the alveodental /t/, and the velar /k/. Three were voiceless, except for /b/, as the Arabic language does not have a voiceless cognate for it. Stop-gap duration for /t/, /t/, /d/, and /d/ (designated plain vs. emphatic) as well as /s/ and /ʃ/ duration (for fricatives) were also measured. (iv) Formant history was assessed to obtain F1 and F2 for three corner vowels /a/, /i/, and /u/.

Statistical analysis

An IBM (International Business Machine Corp., Armonk, New York, USA) compatible personal computer was used to store and analyze the data. Calculations were done by means of Statistical Software Package for the Social sciences (SPSS) version 10, New York, USA. The mean and SD values were calculated. Thereafter, statistical analysis was carried out for each group of dysarthric patients versus the control group using the Student *t*-test, and the *P*-value was calculated. A *P*-value of greater than 0.05 was considered nonsignificant, whereas a *P*-value of less than 0.05 was considered significant. Correlation coefficients between Speech Intelligibility Score, subjective values, and acoustic analysis results for all patient groups were calculated. The mutual correspondence between two values was assessed using the Spearman correlation coefficient.

Results

Tables 1 shows comparison between control groups and dysarthric groups regarding all parameters tested. Tables 2 and 3 show the results of the correlation studies carried out between all parameters tested and speech intelligibility score. Tables 1 shows that the Speech Intelligibility Score was the highest for flaccid dysarthria and the lowest for ataxic. Results revealed significant differences between the control group and each of the studied patient groups for all subjective measures as well as most of the instrumental measures that were included in the study. On comparing the results obtained from all groups under study, the number of unintelligible words was the highest for the hypokinetic group and the lowest for the flaccid group. The number of vowels correct was the highest for the spastic group and the lowest for the hypokinetic group. The number of consonants correct was the highest for the hypokinetic group and the lowest for the flaccid group. Dysphonia grade was the highest for the spastic group and the lowest for the flaccid group. Nasalance Score was the highest for the flaccid group and the lowest for the spastic group. Fundamental frequency was the highest for the ataxic group and the lowest for the hypokinetic group. Jitter was the highest for the flaccid group and the lowest for the ataxic group. Shimmer was the highest for the flaccid group and the lowest for the spastic group (Table 1).

Discussion

Improving speech intelligibility in dysarthric patients is considered the primary goal of therapeutic intervention [15].

Table 1 Comparison between control groups and dysarthric groups

	Control group		Spastic group		Ataxic group		Flaccid group		Hypokinetic group	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Subjective evaluation										
Speech Intelligibility Score	5.00	0.00	2.88[b]	0.99	2.75[b]	0.89	3.38[b]	0.52	3.33[b]	0.52
Speech rate (words per minute)	115.00	5.48	57.50[b]	19.82	64.75[b]	20.75	59.38[b]	13.48	84.50[b]	8.57
No. of unintelligible words per minute	0.00	0.00	23.63[b]	18.50	25.25[b]	14.11	15.38[b]	5.24	32.00[b]	12.65
Dysphonia grade	0.00	0.00	1.88[b]	1.13	1.25[b]	0.71	0.63[b]	0.52	0.83[b]	0.41
Number of consonants correct (out of 28)	28.00	0.00	20.75[b]	3.11	21.38[b]	1.85	19.13[b]	3.48	22.83[b]	1.33
Number of vowels correct (out of eight)	8.00	0.00	6.88[b]	0.99	6.25[b]	0.46	6.25[b]	1.28	5.50[b]	0.55
Objective analysis										
Nasalance Score	16%	4%	24%[b]	2%	29%[b]	1%	55%[b]	14%	25%[b]	1%
Fundamental frequency (Hz)	155.17	50.29	170.13[a]	48.78	172.11[b]	21.16	136.57[a]	29.34	134.38[a]	6.15
Jitter	0.63	0.15	1.54[b]	0.51	0.93[b]	0.32	1.88[b]	0.05	1.25[b]	0.04
Shimmer	0.28	0.17	0.41[a]	0.17	0.42[a]	0.07	0.68[b]	0.01	0.66[b]	0.01
H/*N* ratio	15.43	1.12	2.25[b]	1.56	4.46[b]	2.25	1.86[b]	0.09	2.41[b]	0.05
Average energy for /a/ (dB)	58.57	1.64	57.11[a]	0.60	71.61[b]	6.61	56.83[a]	6.56	58.46[a]	0.36
Duration for /a/ (ms)	267.50	27.25	333.38[a]	127.46	449.23[a]	307.78	340.88[b]	856.44	254.17[a]	7.76
F1 for /a/ (Hz)	585.33	8.80	574.63[a]	29.72	573.75[a]	139.60	651.23[b]	174.51	637.83[b]	8.11
F2 for /a/ (Hz)	1399.9	31.33	1240.0[b]	87.45	1582.5[b]	471.80	3165.2[b]	16.71	1200.0[b]	6.16
F1 for /i/ (Hz)	275.00	17.74	398.50[b]	35.03	339.75[b]	44.20	346.25[b]	19.85	356.17[b]	9.83
F2 for /i/ (Hz)	2601.83	164.33	2230.13[b]	337.41	2280.8[b]	301.39	2028.08[b]	504.74	1915.0[b]	11.58
F1 for /u/ (Hz)	397.00	43.65	375.63[a]	40.29	402.50[a]	46.02	461.66[b]	104.49	401.67[b]	5.54
F2 for /u/ (Hz)	957.33	6.80	911.13[a]	82.51	906.38[a,b]	47.46	1007.32[a]	65.05	863.17[b]	8.95
/b/ VOT (ms)	18.59	4.22	9.25[b]	4.84	13.43[b]	1.49	26.44[b]	2.98	27.50[b]	1.05
/t/ VOT (ms)	26.04	4.89	40.32[a]	17.33	41.09[b]	15.19	19.13[b]	1.64	12.67[b]	1.21
/k/ VOT (ms)	32.89	5.82	65.29[b]	16.61	33.261[b]	14.65	18.76[b]	0.94	26.67[b]	0.82
/d/ stop gap (ms)	74.50	14.05	98.29[b]	17.79	72.23[a]	36.79	137.25[b]	14.37	395.67[b]	8.02
/d̲/stop gap (ms)	68.63	9.69	194.48[b]	77.87	82.14[a]	15.80	150.25[b]	15.22	147.33[b]	4.27
/t̄/ stop gap (ms)	64.60	7.01	144.80[b]	3.69	155.35[b]	85.10	136.25[b]	12.58	178.67[b]	7.42
/t̲/stop gap (ms)	57.90	8.50	188.04[a]	42.65	123.60[b]	49.05	120.63[b]	8.02	161.67[b]	6.83
/s̄/ duration (ms)	129.30	25.32	239.99[a]	63.11	202.29[b]	70.42	199.38[b]	50.38	136.00[a]	5.02
/ʃ/ duration (ms)	144.35	32.08	254.68[a]	6.42	165.33[a]	21.79	282.25[b]	10.29	240.00[b]	3.03

/d̲/, the silent interval on the spectrogram corresponding to articulary closure of the alveodental voiced stop /d/; /t̲/, the silent interval on the spectrogram corresponding to articulatory closure of the alveodental voiceless stop /t/; VOT, voice onset time.
[a]Nonsignificant.
[b]Significant.

Table 2 Correlation coefficients between the Speech Intelligibility Score and various parameters studied for all patient groups

	Intelligibility score			
	Spastic group	Ataxic group	Flaccid group	Hypokinetic group
Subjective evaluation				
Speech rate	0.455[a]	0.944[b]	0.857[b]	−0.994[b]
No. of unintelligible words per minute	−0.860[b]	−0.570[a]	−1.000[b]	−0.980[b]
Dysphonia grade	−0.016[a]	−0.908[b]	−0.204[a]	−0.316[a]
Number of consonants correct	0.824[b]	0.589[a]	0.842[b]	0.971[b]
Number of vowels correct	1.000[b]	0.870[b]	0.269[a]	0.707[a]
Objective analysis				
Nasalance Score	−0.630[a]	−0.701[a]	−0.996[b]	−0.632[a]
Fundamental frequency	−0.570[a]	−0.191[a]	0.984[b]	0.169[a]
Jitter	−0.797[b]	−0.730[b]	−0.985[b]	−0.387[a]
Shimmer	−0.745[b]	−0.827[b]	−0.139[a]	−0.230[a]
H/*N* ratio	0.674[a]	0.209[a]	0.131[a]	0.519[a]
Average energy for /a/	0.661[a]	−0.881[b]	0.767[b]	0.167[a]
Duration for /a/	−0.950[b]	−0.856[b]	−0.950[b]	0.566[a]
F1 for /a/	0.880[b]	0.506[a]	0.999[b]	0.509[a]
F2 for /a/	−0.920[b]	−0.047[a]	−0.642[a]	−0.440[a]
F1 for /i/	−0.574[a]	−0.708[b]	−0.886[b]	−0.250[a]
F2 for /i/	0.738[b]	0.993[b]	0.391[a]	0.067[a]
F1 for /u/	−0.711[b]	−0.991[b]	−0.999[b]	−0.373[a]
F2 for /u/	−0.715[b]	−0.896[b]	−0.917[b]	−0.447[a]
/b/ VOT	0.812[b]	0.471[a]	−0.955[b]	−0.739[a]
/t/ VOT	−0.734[b]	−0.963[b]	0.777[b]	0.107[a]
/k/ VOT	−0.709[b]	−0.991[b]	0.670[a]	0.632[a]
/d/ stop gap	−0.705[b]	−0.854[b]	−0.812[b]	−0.499[a]
/d̲/ stop gap	−0.733[b]	−0.933[b]	−0.893[b]	−0.332[a]
/t̄/ stop gap	−0.738[b]	−0.838[b]	−0.894[b]	−0.487[a]
/t/ stop gap	−0.713[b]	−0.871[b]	−0.719[b]	−0.472[a]
/s̄/ duration	−0.708[b]	−0.903[b]	−0.991[b]	−0.309[a]
/ʃ/ duration	0.523[a]	−0.892[b]	−0.878[b]	−0.000[a]

VOT, voice onset time; _, signifies negative correlation.
[a]Nonsignificant.
[b]Significant.

The aim of this study was to examine some of the contributing factors to reduced speech clarity in these patients using perceptual as well as instrumental techniques. Results revealed common speech characteristics among the studied patient groups. These included reduced speech intelligibility, decreased speech rate, increased number of unintelligible words, lower number of vowels correct, greater Nasalance Score, greater jitter, greater shimmer, and a low *H*/*N* ratio.

Dysarthric patients usually exhibit changes in speech rate that include slower, excessively faster, or variable rate of speech [5]. This can be attributed to the pathophysiology and neuromuscular problems, which include weakness, incoordination in ataxic patients, and rigidity in hypokinetic patients. In a previous study, the speech of a group of dysarthric patients was analyzed and results revealed reduced movement speed [16]. Similar findings were reported in individuals with hypokinetic dysarthria [17]. In the current research, the speech rate of the four dysarthric groups under study was calculated and its correlation with speech intelligibility was studied. Results revealed a significant reduction in the speech rate in all patient groups as compared with the healthy control group. Further correlation analysis revealed a significant positive correlation between speech rate and speech intelligibility in the ataxic and flaccid groups. In contrast, a significant negative correlation was found between speech intelligibility and rate in the hypokinetic group. This is in agreement with the results obtained previously by other researchers [5], who found a negative correlation between speech rate and speech intelligibility in hypokinetic patients and a positive correlation between speech rate and speech intelligibility in ataxic and flaccid groups.

Although dysphonia was observed in all patient groups, this did not seem to have a major effect on speech intelligibility as revealed by the nonsignificant correlation results obtained, except for the ataxic group, in which a significant negative correlation was found between speech intelligibility and dysphonia.

The number of unintelligible words per minute was significantly higher for all the patient groups compared with the control group. This is related to irregular articulatory breakdowns and imprecise consonants.

There is usually a variety of oromotor disorders in dysarthric patients, including reduced or variable range and speed of movement, involuntary movements, and abnormal tone. This explains the significant reduction in the number of consonants correct and number of vowels correct in the dysarthric groups. A significant positive correlation was found between speech intelligibility and number of correct consonants and vowels, except for ataxic dysarthria in which the number of correct consonants did not show a significant correlation with speech intelligibility, and the hypokinetic and flaccid groups in which the number of correct vowels did not show a significant correlation with speech intelligibility.

The significant increase in the Nasalance Score obtained in the spastic group was most probably due to velar

Table 3 Summary of significant correlation results obtained between various parameters studied and Speech Intelligibility Scores across all patient groups studied

	Significant positive correlation with the Speech Intelligibility Score	Significant negative correlation with the Speech Intelligibility Score
Spastic group	Number of consonants correct Number of vowels correct F1 of /a/ F2 of /i/ /b/ VOT	Number of unintelligible words per minute Shimmer Jitter Duration of /a/ F2 of /a/ F1 of /u/ F2 of /u/ VOT of /t/, /k/ Stop gap of /t/, /t̲/, /d/, /d̲/ Duration of /s/
Ataxic group	Speech rate Number of vowels correct F2 of /i/	Shimmer Dysphonia grade Jitter Average energy of /a/ Duration of /a/ F1 of /i/ F1 of /u/ F2 of /u/ VOT of /t/, /k/ Stop gap of /t/, /t̲/, /d/, /d̲/ Duration of /s/ and /ʃ/
Flaccid group	Speech rate	Number of unintelligible words per minute
	Number of consonants correct	Nasalance Score
	Fundamental frequency Average energy of /a/ F1 of /a/ VOT of /t/	Jitter F1 of /i/ F1 of /u/ F2 of /u/ VOT of /b/ Stop gap of /t/, /d̲/, /d/, /d̲/ Duration of /s/ and /ʃ/
Hypokinetic group	Number of consonants correct	Speech rate
		Number of unintelligible words per minute

VOT, voice onset time.

spasticity and sluggish mobility. Other researchers also proved that hypernasality devoid of nasal emission of air can be considered a salient feature of spastic dysarthria [18]. A significant increase in the Nasalance Score, attributable to incoordination and disordered timing of velar, was also observed in ataxic patients [19]. The significant increase in the Nasalance Score obtained in the flaccid group can be attributed to reduced velar movement [18]. A significant increase in the Nasalance Score was also found in the hypokinetic dysarthric group secondary to muscle rigidity and akinesia. This agrees with other studies in which hypernasality in patients with hypokinetic dysarthria has been reported [20]. Correlation studies revealed a negative correlation between the Nasalance Score in flaccid dysarthria and the Speech Intelligibility Score, which implies that hypernasality acts as a major contributing factor to speech unintelligibility in such patients. Some researchers believe that hypernasality, associated with nasal emission of air, is the most prominent feature of flaccid dysarthria, whereas in spastic dysarthria hypernasality is not accompanied by nasal emission of air [18].

The acoustic changes observed in dysarthric patients can reflect the articulatory difficulties and compensatory strategies that were not easily identified by global perceptual judgment. Nonsignificant differences were found between the patient groups and the control group regarding F0, except for the ataxic group, in which F0 was found to be significantly higher than that in the control group. In flaccid dysarthria, a significant positive correlation was found between fundamental frequency and speech intelligibility, which, in turn, can imply its importance as a contributing factor to speech clarity in these patients.

Jitter was found to be significantly higher in all patient groups and shimmer was found to be significantly higher in the flaccid and hypokinetic groups, reflecting the neurological changes that occur in the vocal folds.

The significant increase in jitter obtained in spastic patients can be attributed to bilateral spastic paralysis of the laryngeal muscles. Correlation studies revealed a significant negative correlation between jitter and speech intelligibility in spastic dysarthria, which agreed with studies of other researchers who found abnormal values of jitter in spastic dysarthria [21]. A significant increase in jitter was also found in ataxic dysarthria. This is most probably due to defective laryngeal muscle coordination. This also agrees with the opinion other researchers who believe that jitter is the most frequent abnormality in ataxic dysarthria [22]. The significant increase in the jitter in flaccid dysarthria can be attributed to inadequate vocal-fold adduction. In contrast, the significant increase in jitter in the hypokinetic group can be attributed to rigidity of the laryngeal muscles. The significant increase in shimmer obtained in the flaccid group can be attributed to inadequate vocal-fold adduction and insufficient subglottic pressure [23].

A negative correlation was found between jitter and speech intelligibility in all patient groups studied (except for the hypokinetic group). As for shimmer, a significant negative correlation was found between speech intelligibility and shimmer in spastic and ataxic groups. However, no significant correlation was found between shimmer and speech intelligibility in flaccid and hypokinetic groups.

Results showed a significant decrease in the *H*/*N* ratio in all the dysarthric groups. Similar findings were obtained by other researchers who reported a reduced *H*/*N* ratio in spastic, flaccid, ataxic, and hypokinetic dysarthria [20]. However, correlation studies revealed nonsignificant results between speech intelligibility and the *H*/*N* ratio for all patient groups.

Estimated duration of the vowel /a/ in the dysarthric groups revealed that its duration may vary, and this agrees with other studies that revealed long, short, or inappropriately scaled vowel duration in dysarthric patients [9].

A general rule in relating vowel articulation to vowel formant frequencies is that F1 varies mostly according to tongue height, whereas F2 varies according to tongue advancement. In dysarthria, vowels may be perceived as being produced in an abnormal way by the patients, which in turn reduces speech intelligibility. This is because the tongue usually acquires a low position in high vowel, high position in low vowels, front position in back vowels, or back position in front vowels, leading to loss of vowel contrast, thereby reducing speech intelligibility [24].

From the correlation studies, it could be deduced that that speech intelligibility in spastic, flaccid, and ataxic dysarthria was negatively affected by changes in most of the studied formants. However, this did not hold true for the hypokinetic group.

In a previous study, acoustic analysis of the vowel /a/ revealed a significant increase in average energy due to incoordination and difficulties in regulating the force and speed of the articulatory organs [19]. In the current study, a significant negative correlation was found between speech intelligibility and the average energy of /a/ for the ataxic group. However, a significant positive correlation was found between speech intelligibility and the average energy of /a/ for the flaccid group. This indicated that increased loudness, or what could be subjectively heard as loudness outbursts secondary to lack of loudness control in ataxic dysarthria, can negatively affect speech clarity in patients with ataxic dysarthria. In contrast, reduced loudness – secondary to lack of adequate buildup of subglottic pressure due to vocal-fold weakness – may be among the factors affecting speech clarity in patients with flaccid dysarthria. Helping these patients raise the level of their voice loudness can thus aid in improving their speech clarity.

Acoustic results obtained in the current study may imply low positioning of the tongue, which, in turn, led to an increase in F1 values [18]. However, the reduced F2 values reflected restriction in anteroposterior displacement in the tongue. This is related to the reduced amplitude of voluntary movements and limited range of movement [25].

VOT is commonly used as an index of the temporal coordination of the movements of the vocal folds and the oral structures and thus reflects interarticulatory synchronization [26]. In the current study, VOT was found to be long in spastic dysarthria secondary to spasticity, weakness, and limited range of movement. Some of the earlier research studies have revealed prolonged VOT in spastic dysarthria [27], whereas others have revealed reduced VOT [8]. High interspeaker as well as intraspeaker variability in the VOT has also been reported in ataxia [26] and flaccid dysarthria [28]. Correlation studies have revealed a significant correlation between VOT of /t/ and speech intelligibility in ataxic, spastic, and flaccid dysarthria. Similar findings were obtained with regard to VOT of /k/ for spastic and ataxic groups. As for /b/, correlation studies between VOT and Speech Intelligibility Score were found to be significant only for the spastic group (a significant positive correlation) and the flaccid group (a significant negative correlation). These findings are in accordance with the results obtained by other researchers whose studies have also proven the negative influence changes in VOT can have on speech intelligibility [29].

The stop-gap duration for /t/ and /t̲/ was significantly longer in most of the dysarthric groups as compared with the control group. This was once again related to articulatory weakness, spasticity, hypotonia, rigidity, and/or incoordination. The increase in stop gap is expected to lead to an increase in the duration of stops as a whole, which would, in turn, negatively affect speech intelligibility. This partially explains the negative correlation found between stop gap duration and speech intelligibility in all dysarthric groups – except the hypokinetic group – and it agrees with previous studies in which longer segment duration was found to be a characteristic feature of disordered speech [26].

A significant increase in the /s/ duration was found in the ataxic and flaccid groups. In contrast, a significant increase in the /ʃ/ duration was found in the flaccid and hypokinetic groups. This can be attributed to the slow as well as reduced range of articulatory movements. A negative correlation was found between /s/ duration and speech intelligibility in all dysarthric groups studied (except the hypokinetic group). This is in accordance with other research findings where /s/ duration was found to be negatively correlated with speech intelligibility in dysarthria [30]. However, a significant negative correlation was found between /ʃ/ duration and speech intelligibility in ataxic and flaccid groups.

From the findings obtained previously, it is clear that factors affecting speech intelligibility in dysarthric patients can vary from one type of dysarthria to the other.

Conclusion and implications

(1) In the spastic group, speech intelligibility was found to be positively correlated with correct speech sound production, F1 of /a/, F2 of /i/, and VOT of /b/. However, it was found to be negatively correlated with the number of unintelligible words per minute, jitter, shimmer, duration and F2 of /a/, F1 and F2 of /u/, VOT of /t/, /k/, stop gap duration of /t/, /t̲/, /d/, and /d̲/, and duration of /s/.
(2) In the ataxic group, speech intelligibility was found to be positively correlated with speech rate, correct vowel production (in contrast to the spastic group, no correlation was found with correct consonant production), and F2 of /i/. In contrast, speech intelligibility was found to be negatively correlated with dysphonia grade, jitter, shimmer, average energy, and duration of /a/, F1 of /i/ and /u/, F2 of /u/, VOT of /t/, /k/, stop gap duration of /t/, /t̲/, /d/, and /d̲,/ and duration of /s/ and /ʃ/.
(3) In the flaccid group, speech intelligibility was found to be positively correlated with the speech rate, correct consonant production, average energy of /a/, F1 of /a/, and VOT of /t/. However, speech intelligibility was found to be negatively correlated with the number of unintelligible words per minute, Nasalance Score, jitter, F1 of /i/ and /u/, F2 of /u/, VOT of /b/, stop-gap duration of /t/, /t̲/, /d/, and /d̲/, and duration of /s/ and /ʃ/.

(4) In the hypokinetic Parkinsonian group, speech intelligibility was found to be positively correlated with correct consonant production. However, speech intelligibility was found to be negatively correlated with speech rate and number of unintelligible words per minute.

(5) It is recommended that these findings are taken into consideration while designing therapy programs for these patients. This can aid in promoting their overall speech intelligibility. In addition, it can help in monitoring any subtle progress or deterioration achieved.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

References

1 Kent RD. Hearing and believing: some limits to the auditory-perceptual assessment of speech and voice disorders. Am J Speech Lang Pathol 1996; 5:7–23.

2 Shipley KG. *Assessment in speech–language pathology: a resource manual*. San Diego, CA: Singular Pub. Group; 1992.

3 Gerralt B, Til J, Rosenbek J, Wertz R, Boysen A. In: Pauh H, editor. *Use and perceived value of perceptual and instrumental measure in dysarthria management.* Baltimore: Brookes Publishing Company; 1991.

4 Mary GB. Assessing intelligibility: children's expressive phonologies. Top Lang Disord 1994; 14:17–25.

5 Yorkston KM, Breukelman DR. Communication efficiency of dysarthric speakers as measured by sentence intelligibility and speaking rate. J Speech Hear Disord 1981; 46:296–301.

6 Hartelius L, Runmarker B, Andersen O. Prevalence and characteristics of dysarthria in a multiple-sclerosis incidence cohort: relation to neurological data. Folia Phoniatr Logop 2000; 52:160–177.

7 Kent RD, Kent JF, Duffy JR, Thomas JE, Weismer G, Stuntebeck S. Ataxic dysarthria. J Speech Hear Res 2000; 43:1275–1289.

8 Hardcastle WJ, Gibbon F. Electropalatography and its clinical applications. In: Ball MJ, Code C, editors. *Instrumental clinical phonetics*. London: Singular Pub. Group; 1997. pp. 149–193.

9 Caruso AJ, Burton EK. Temporal acoustic measures of dysarthria associated with amyotrophic lateral sclerosis. J Speech Hear Res 1987; 30:80–87.

10 Conder E. *An investigation of fundamental frequency, maximum frequency phonation range, frequency perturbation and pathological phonation Independent study*. Hunter College. New York City, USA: Institute of Electrical and Electronic Engineers; 1988.

11 Kent RD, Rosenbek JC. Prosodic disturbance and neurologic lesion. Brain Lang 1982; 15:259–291.

12 Ohde R, Sharf DJ. *Phonetic analysis of normal and abnormal speech*. University of Michigan, Merrill; 1992.

13 Turner GS, Tjaden K, Weismer G. The influence of speaking rate on vowel space and speech intelligibility for individuals with amyotrophic lateral sclerosis. J Speech Hear Res 1995; 38:1001–1013.

14 Kotby MN. Voice disorders: recent diagnostic advances. Proceedings of Annual Ain-Shams Medical Congress; Cairo, Egypt, March 1–6; 1992.

15 Schulz GM, Grant MK. Effects of speech therapy and pharmacologic and surgical treatments on voice and speech in Parkinson's disease: a review of the literature. J Commun Dis 2000; 33:59–88.

16 Yunusova Y, Weismer G, Westbury JR, Lindstrom MJ. Articulator movements during vowels in speakers with dysarthria and healthy controls. J Speech Lang Hear Res 2008; 51:596–611.

17 Ludlow CL, Connor NP, Bassich CJ. Speech timing in Parkinson's and Huntington's disease. Brain Lang 1987; 32:195–214.

18 Freed DB. *Motor speech disorders: diagnosis & treatment*. California State University, Fresno: Cengage Learning; 2000.

19 Duffy JR, Clinic M. *Motor speech disorders: substrates, differential diagnosis and management*. 2nd ed. Saint Louis: Mosby; 2005.

20 Shohdi S, Khalifa S, Abou Elezz A. *Assistive diagnostic measures of voice and speech disorders in dysarthric patients*. Cairo University: Faculty of Medicine; 1995.

21 Jaeger M, Fröhlich M, Hertrich I, Ackermann H, Schönle PW. Dysphonia subsequent to severe traumatic brain injury: comparative perceptual, acoustic and electroglottographic analyses. Folia Phoniatr Logop 2001; 53:326–337.

22 McHenry M. Acoustic characteristics of voice after severe traumatic brain injury. Laryngoscope 2000; 110:1157–1161.

23 Kent RD, Vorperian HK, Duffy JR. Reliability of the multi-dimensional voice program for the analysis of voice samples of subjects with dysarthria. Am J Speech Lang Pathol 1999; 8:129–136.

24 Bunton K. Fundamental frequency as a perceptual cue for vowel identification in speakers with Parkinson's disease. Folia Phoniatr Logop 2006; 58:323–339.

25 Weismer G, Yunusova Y, Westbury JR. Interarticulator coordination in dysarthria: an X-ray microbeam study. J Speech Lang Hear Res 2003; 46:1247–1261.

26 Kent RD, Kim YJ. Toward an acoustic typology of motor speech disorders. Clin Linguist Phon 2003; 17:427–445.

27 Farmer A. Voice onset time production in cerebral palsied speakers. *Folia Phoniatr*. 32 Basel; 1980. pp. 267–273.

28 Morris RJ. VOT and dysarthria: a descriptive study. J Commun Dis 1989; 22:23–33.

29 Liu HM, Tseng CH, Tsao FM. Perceptual and acoustic analysis of speech intelligibility in Mandarin-speaking young adults with cerebral palsy. Clin Linguist Phon 2000; 14:447–464.

30 Chen H, Stevens KN. An acoustical study of the fricative /s/ in the speech of individuals with dysarthria. J Speech Hear Res 2001; 44:1300–1314.