Distinguishing between dysarthria types based on acoustic parameters

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Abstract

Dysarthria is a motor speech disorder resulting from neurological impairments. Because of the variability of impairments and disordered speech characteristics, it is useful to categorize it into types. The current study gives an overview of the main types of dysarthria, describing the different underlying causes, some disordered speech characteristics arising from those impairments, as well as the corresponding acoustic parameters, and some possible methods to measure the most relevant acoustic features. Six main groups of acoustic parameters were identified that could help distinguish between the types of dysarthria. Since the properties of the acoustic signal are connected to the manner of articulation, which is dependent on the neuromuscular system, the precise description of acoustic features of dysarthric speech could provide valuable information that could aid localization and differential diagnosis.

1. Introduction

"Motor speech disorders can be defined as speech disorders resulting from neurologic impairments affecting the planning, programming, control, or execution of speech" (Duffy, 2013). Dysarthria is a collective name for a group of motor speech disorders that reflect abnormalities in the movements required for speech production. Depending on the localization and severity of the impairment, neuromuscular deficits may affect any or all of the respiratory, phonatory, resonatory, and articulatory components of speech, or they may affect a single component only (Ackermann et al., 2010). Due to the diversity of the possible underlying deficits, perceived speech abnormalities are heterogeneous, so in order to describe, understand and manage dysarthria successfully, it is

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Beszédtudomány – Speech Science 2024/1. 118–135. DOI: 10.15775/Besztud.2024.1.118-135

helpful to categorize it into types. The most widely used categorization was first established by Darley et al. (1969a; 1969b), who delineated five types of dysarthria: flaccid, spastic, ataxic, hypokinetic, and hyperkinetic, as well as a sixth, mixed type. Their categorization was based on 38 dimensions or speech features, using perceptual methods. This grouping based on the combination of functional speech deficits was adopted by Duffy (2013) who added a new type, called unilateral upper motor neuron (UUMN) dysarthria. An advantage of this categorization is that the described speech features (e.g., hypernasality) can be directly tied to neuroanatomical deficits, so the precise description of speech characteristics can provide information about the localization of impairment. Successful categorization of the dysarthrias can therefore have implications for the localization and diagnosis of the underlying neurological disorder and can aid the clinical management process (Duffy, 2013).

Dysarthria assessment can be done in many ways (using perceptual, acoustic or physiological methods), the most widely used method is the perceptual, as it has several advantages. First, it costs significantly less than instrumental methods; second, a speaker's intelligibility can be easily assessed perceptually, third, different dysarthria types can be distinguished with a high success rate. However, there are some disadvantages to this method, such as its high subjectivity, being difficult to standardize, and providing limited information about the pathophysiological background of the perceived speech characteristics (Cummings, 2008).

In contrast, acoustic methods can provide objective, quantifiable measurements that may confirm perceptual judgements on one hand or highlight aspects of dysarthric speech that could not be measured perceptually on the other. Acoustic analyses of the different types of dysarthria have generally two main goals: first, identifying the exact aspects of the acoustic signal related to intelligibility deficits in dysarthria, and second, providing a precise description of the different types' acoustic profiles (Kim et al., 2011). Despite these advantages, there are some drawbacks to acoustic analyses as well. One such disadvantage is the possible difference between the most salient speech characteristics identified using perceptual and acoustic methods, for example, loudness or pitch abnormalities measured instrumentally may not be perceived by listeners (Kent et al., 1999).

This paper aims to give a general description of the acoustic profiles of the different types of dysarthria with special attention to the most relevant acoustic features in terms of distinguishing between the types. Furthermore, we attempt to give an overview of the neurological impairments underlying speech deficits in dysarthria, and how these speech abnormalities can be described with acoustic analysis. The paper is structured as follows. The next section introduces the six main types of dysarthria, from the underlying impairments to the speech characteristics. Section 3 describes the main methods of acoustic analysis that could be used to differentiate the types of dysarthria, and summarizes the methods and results of some recent empirical studies examining the acoustic differences between the types. Finally, Section 4 gives a brief summary and mentions possible future work.

2. The types of dysarthria

2.1. Flaccid dysarthria

The main distinguishing speech characteristics of flaccid dysarthria are due to muscle weakness and reduced muscle tone. Speech abnormalities can be present in any or all of the components of speech. The condition is the result of the impairment of one or more cranial or spinal nerves caused most commonly by trauma. Other possible causes include congenital, infectious or inflammatory, degenerative, and vascular diseases. The affected muscle groups depend on the lesion loci, sometimes involving only a single muscle group, which can aid the localization. The most noticeable speech deviations in this type are caused by vagus nerve (cranial nerve X) lesions, which supplies most of the muscles of the pharynx, the soft palate, and the larynx. Vagus nerve lesions can cause weakness in the soft palate, diminishment of the gag reflex, and nasal regurgitation among others. These changes can manifest in speech as aphonia, reduced loudness, reduced pitch, hypernasality, nasal emission, hoarseness, stridor (audible inhalation), and diplophonia (double pitch phonation). Other speech features of this type include short phrases, monotonous pitch and loudness, and imprecise consonants. The latter cannot be tied to the lesion of a single cranial nerve (Duffy, 2013).

2.2. Spastic dysarthria

The hallmark symptom of this type is the combination of weakness and spasticity, caused by bilateral damage to the direct and indirect activation pathways of the central nervous system. The indirect activation pathways are responsible for reflexes, maintaining posture, regulating muscle tone, and give a framework for skilled movements. Their activation can have an inhibitory role. Damage to these pathways mostly affects their inhibitory role, the results are overactivity, manifesting as increased muscle tone, spasticity, and hyperactive reflexes. Direct activation pathways serve a facilitatory role, they are related to skilled, fine movements. Their damage causes loss or impairment of said fine movements. Underlying conditions causing damage to the activation pathways are generally vascular (e.g., stroke), degenerative or traumatic. As opposed to flaccid dysarthria, where individual muscle groups are affected, flaccid dysarthria can be characterized as the impairment of movement patterns, as the affected areas are tied to motor control. As a result, deficits arise in all components of speech (Duffy, 2013). Darley et al. (1969b) grouped the most notable disordered speech characteristics of spastic dysarthria into four clusters. The first cluster, prosodic excess includes slow rate and excess and equal stress. The second cluster is called articulatory-resonatory incompetence, and it consists of imprecise consonants, distorted vowels, and hypernasality. The third cluster, prosodic insufficiency, includes features such as monopitch, monoloudness, reduced stress, and short phrases. Finally, the fourth cluster, phonatory stenosis, covers low pitch, harshness, strained-strangled voice, pitch breaks, short phrases, and slow rate. Although imprecise consonants are the most salient feature of spastic dysarthria, they can be found in all main types of dysarthria and can not be used as a distinguishing speech characteristic of this type (Duffy, 2013).

2.3. Ataxic dysarthria

Ataxic dysarthria is characterized by incoordination resulting from damage to the cerebellar control circuit. Speech abnormalities can affect all levels of speech, but are most notable in articulation and prosody (Duffy, 2013). The cerebellum influences the motor system in multiple ways, for example it plays a role in the timing of movement components, regulating the scale of movements and muscle contractions for fine movements (Laforce & Doyon, 2001). Damage to the area is caused most often by degenerative disease, but demyelinating, vascular, traumatic or toxic diseases are not uncommon either. Failure to coordinate or control movement patterns have an effect on speech too, that is why a distinguishing characteristic of ataxic dysarthria is the irregularity of alternating motion rates (AMRs, that is, the repetition of one syllable as steadily as possible). Darley et al. (1969a) identified three clusters of disordered speech characteristics in this type. The first cluster is called articulatory inaccuracy, it can be characterized by imprecise consonants, irregular articulatory breakdowns, and vowel distortions. The second cluster, prosodic excess, includes excess and equal stress, prolonged phonemes, prolonged intervals, and slow rate. Lastly, the third cluster is phonatory-prosodic insufficiency, and it consists of harshness, monopitch, and monoloudness.

2.4. Hypokinetic dysarthria

The most prominent characteristics of hypokinetic dysarthria are rigidity, reduced force and range of movement, and slow individual but fast repetitive movements, which can affect any or all levels of speech. It is caused by damage to the basal ganglia control circuit, and is most often, but not always associated with Parkinson's disease (PD). The functions of the basal ganglia control circuits include regulating muscle tone, stabilizing posture during fine movements, regulating movements supporting goal-oriented activities, regulating force, amplitude and duration of movements, and adjusting movements to the environment. Damage to these circuits can lead to reduction of movement or the inability to inhibit involuntary movement. Resulting speech abnormalities include weak voice, hoarseness or breathiness, fast rate, syllable repetition, rapid and blurred AMRs (Duffy, 2013). Darley et al. (1969b) named only one cluster of speech abnormalities associated with this type. The cluster of disordered speech characteristics is called prosodic insufficiency and is characterized by monopitch, monoloudness, reduced stress, short phrases, variable rate, short rushes of speech, and imprecise consonants.

2.5. Hyperkinetic dysarthria

Speech abnormalities in hyperkinetic dysarthria are due to rhythmic or irregular, slow or fast involuntary movements. It is also caused by damage to the basal ganglia control circuits, resulting in deviations in any or all components of speech, which are most notable in prosody and rate. Hyperkinetic speech can give the impression that speech production starts out normally, but is distorted, slowed or interrupted by involuntary movements. As mentioned above, lesions of the basal ganglia control circuits can lead to the failure of inhibition of involuntary movements, as well as voluntary movements being slowed down. The groups of caused involuntary movements are heterogeneous, e.g., dyskinesia (a broad category of abnormal involuntary movements), myoclonus (quick contraction of muscle groups), tics (quick, stereotypical, patterned movements), chorea (quick, irregular, random movements), tremor (rhythmic movement of a body part), and dystonia (excessive contraction of muscles). Resulting speech abnormalities depend on the type of involuntary movements, and therefore they can be diverse as well. To name a few, hyperkinetic speech characteristics include prolonged intervals, strained voice quality, hypernasality, tremor, and slow and irregular AMRs (Duffy, 2013).

2.6. Unilateral upper motor neuron (UUMN) dysarthria

This type shows effects of weakness, sometimes spasticity and incoordination. Disordered speech characteristics can manifest in any or all levels of speech, most often notable in articulation, phonation, and prosody. In contrast to all other types, this type is characterized based on anatomy, the underlying cause is always damage to the upper motor pathways. This type has received limited attention, since its symptoms can be mild, recovery can be quick, and as a result, it is difficult to conduct research on it (Ackermann et al., 2010). The upper motor neuron system is bilateral, its pathways pass signals to cranial and spinal nerves which are related to muscles that play a role in speech production. Several nerves (such as the trigeminal or the vagus) receive both contralateral and ipsilateral innervation, which allows to preserve breathing, feeding, and speech functions in the case of unilateral lesions. In some cases, however, unilateral damage can result in unilateral facial weakness, weakness of the jaw, palate, vocal fold, and most noticeably the tongue. The most common possible etiology is stroke, but tumor and trauma are also frequent (Duffy, 2013). The most apparent speech deficits in this type are imprecise consonants, irregular articulatory breakdowns, and irregular, slow or imprecise AMRs. Phonatory abnormalities, such as hoarseness and decreased loudness are also described (Duffy & Folger, 1996).

3. Acoustic features relevant to distinguishing between dysarthria types

This section aims to describe how the most relevant distinguishing features among the types of dysarthria can be measured with acoustic analysis. Drawing conclusions from the essential literature (Darley et al., 1969a,b; Duffy, 2013) and the results of some recent empirical studies we can name six main clusters of disordered speech characteristics based on the acoustic parameters that are involved. These clusters and some specific characteristics covered by them are the following. (1) Temporal characteristics (slow or fast rate, prolonged intervals, silences), (2) Changes in pitch (monopitch, pitch break, stress irregularities), (3) Changes in intensity (reduced loudness, monoloudness, loudness variability), (4) Changes in articulation (imprecise vowels and/or consonants), (5) Nasal resonance (hypernasality, nasal emission), (6) Changes in voice quality (harshness and breathiness). This categorization partially follows the three main acoustic domains (frequency, duration, and intensity), and can partially be described as a combination of them. The descriptions of these characteristics are followed by brief overviews of some recent empirical studies which relied on said features. For the sake of brevity, we only mention studies where the discussed acoustic features ranked as the most important or highly relevant features when distinguishing dysarthria types.

3.1. Temporal characteristics

Measuring speech properties pertaining to the time domain seems to be the most straightforward. The necessary procedures include segmenting the appropriate speech units (e.g., phonemes or syllables) with care based on the waveform and spectrogram, the duration of these intervals can be measured automatically using an acoustic analysis software (e.g. Praat, Boersma & Weenink, 2023). Automatic segmentation of dysarthric speech may have limitations, and therefore it is advised to manually correct the outcome. It could be fruitful to carry out intraspeaker, as well as interspeaker comparisons between different phoneme durations, as the duration of different phonemes can be affected diversely. Examining differences in such durations can aid identify the factors underlying intelligibility deficits, and the localization of neuroanatomical impairment (Kent et al., 1999). Another frequently measured property is the duration of syllables, which should be compared to the duration of silences to obtain the speech rate and the possible irregularities thereof. The preferred method for this is called the diadochokinesis (DDK) test, which is a method used to detect irregularities in rapid alternating movements, testing speech motor ability (Juste et al., 2012).

Fougeron et al. (2022) aimed to differentiate between flaccid, hypokinetic, ataxic and two mixed (amyotrophic lateral sclerosis [ALS] and Wilson-syndrome) dysarthric French speech using a complex feature set. The differentiation was based on seven dimensions describing intelligibility, articulation, maximum phonation time, voice, prosodic contrast, speech rate, and diadochokinetic rate. Out of all features, DDK rate proved to be the most informative one, most successfully distinguishing the ataxic and one mixed (ALS) group from the rest. Kim et al. (2011) classified English speakers based on eight acoustic features. The study represented all types identified by Duffy (2013). They found that one of the two main contributors to type classification was articulation rate. Lowit and Kuschmann (2012) focused on intonation combined with temporal measures in hypokinetic and ataxic English speakers. Among others, their results showed faster speech rate for the hypokinetic group compared to the ataxic group. Liss et al. (2009) focused on differences in speech rhythm between four English speaking dysarthric groups (ataxic, hypokinetic, hyperkinetic, and mixed flaccid-spastic). The recordings were analyzed along the lines of eleven parameters, such as articulation rate or the standard deviation of vocalic intervals. The results revealed that hypokinetic speakers had normal or fastened speech rate, the mixed group showed slow and prolonged speech, and in the case of hyperkinetic dysarthria, vocalic intervals showed high variability. As for ataxic speech, rather than finding one or two prominent parameters, it is the combination of features that leads to successful differentiation. Nishio and Niimi (2001) examined speech rate and its components in Japanese speakers, comparing all dysarthria types described by Duffy (2013). The analyzed features were speaking rate, articulation rate, and speech/pause ratio. According to the results, the flaccid and hypokinetic group had similar articulation rate to the control group, however, these two groups had the highest speech/pause ratio. The slowest speaking rate was observed in the spastic and mixed groups, the slowest articulation rate belonged to the mixed group. Finally, Kis et al. (2020) analyzed the speech rate of Hungarian dysarthric speakers, grouping the subjects based on etiology (Parkinson's disease, stroke, and sclerosis multiplex). The results of diadochokinesis tests showed significant differences between all three groups: the PD group's speech rate was the highest, while the stroke group's speech rate was the lowest in every task.

3.2. Changes in pitch

Several deviations in speech can be described with the examination of the pitch, which is the human perception of the fundamental frequency (F0). It influences whether a voice is perceived as high or low, and its alteration plays a role in suprasegmental features such as stress and intonation. Its deviations can be measured as follows. Monopitch, that is, reduced stress or intonation manifests as a flat F0 contour, irregularities in stress or intonation mean abnormal F0 patterns, perceived low pitch is related to a low frequency F0, and pitch break is a silent interval within the pitch contour. Voice tremor manifests in the rhythmic oscillation of F0, the frequency of these oscillations depends on the underlying condition causing the tremor. Due to the diversity of its alterations, F0 is analyzed along the lines of numerous parameters, such as statistical properties (mean, mode, standard deviation), F0 contour, jitter, and tremor (Kent et al., 1999; Ball & Lowry, 2001; Ball, 2021). When analyzing the fundamental frequency, it is necessary to keep in mind the demographic data of the speaker (age, sex), as these have a high influence on the pitch, consequently, comparison should be made only between members of the same demographic group.

F0 was one of the main contributors to type classification when comparing all dysarthria types in the study of Kim et al. (2011). Thoppil et al. (2017) analyzed vowel formants in three types of dysarthria: ataxic, spastic, and extrapyramidal (the latter could be hypokinetic, hyperkinetic or UUMN dysarthria) using speech samples of Malayalam speakers. The examined the values of the fundamental frequency, the first two formants, and pitch break. The authors report that F0 jitter and flat F0 were mostly found in the extrapyramidal group, and pitch break is most common among ataxic speakers. Lowit and Kuschmann (2012) conducted a variety of intonation measures, such as the mean length of intonation phrases or the syllable–pitch-accent ratio. They found significant between-group differences, such as a higher number of rising pitch accents for ataxic speakers.

3.3. Changes in intensity

Intensity is proportional to amplitude and is related to perceived loudness. We can describe general characteristics of loudness with the attributes of intensity (highest, lowest or mean value), while its monotonicity or excess variability manifest as abnormalities in the intensity contour. Analyzing intensity could be important not only because it describes loudness but also because examining it along with temporal and pitch-related features gives us valuable information about prosody. Analyzing these three parameters is especially advantageous when studying dysarthric speech, since prosodic alterations are common, yet different in nature in the different types. It is worth noting that stress is produced differently in different languages by changing either one or a combination of the three parameters of duration, pitch and intensity (Gósy, 2004), so when analyzing dysarthric speech we should be aware of the stress patterns of the language spoken by the person. By looking at stress patterns we will also be able to examine speech rhythm, which is the pattern of alternating stressed and unstressed syllables (Kent & Read, 2002).

3.4. Changes in articulation

Measuring the quality of articulation is a complex task, as it depends on the type of analyzed phonemes (e.g., vowels or consonants), as well as on the analyzed attributes (e.g., the alteration of the manner or place of articulation). The most common measures for vowel analysis include the values of the first three formant (F1, F2, F3) frequencies, F1–F0 difference value, F2–F1 difference value, and formant frequency fluctuation (Kent et al., 1999). These values are especially informative in the case of dysarthria, because they are related to the horizontal and vertical movements of the tongue. By measuring the frequencies of vowel formants, we can describe centralization, vowel space reduction, and abnormal formant frequencies. Since consonants form a heterogenous group, we should distinguish sonorants from obstruents, studies on the latter being more common in the case of dysarthria (Kent et al., 1999). From the point of view of dysarthria research, spectral moment analysis can be a useful approach, the value of the first spectral moment being the most informative (Kim et al., 2011). Another promising metric is the slope of F2 transition in consonant-vowel sequences, which can be tied to overall intelligibility (Kent et al., 1999). The precision of the articulation of stop consonants can be described partially by the acoustic energy present during the occlusive phase. The occlusive phase is normally almost perfectly silent, but in the case of some dysarthric speakers (especially those with Parkinson's disease) produce energy during this phase. This can happen in two ways: incomplete closure can cause turbulence noise (spirantization), and laryngeal dysfunction can cause voicing (Kent et al., 1999). Lansford and Liss (2014) focused on vowel acoustics, comparing four groups of English speakers (ataxic, hypokinetic, hyperkinetic, and a mixed flaccid-spastic). Measurements were made using the first two formant frequencies of ten different vowels. F2 slope metrics (average F2 slope and F2 slope of the most dynamic vowels) showed significant differences between the groups. The hypokinetic group had greater average F2 slopes than the ataxic or the mixed group, as did the hyperkinetic group compared to the mixed group. Fougeron et al. (2022) found that the quality of articulation was one of the most relevant features when differentiating between flaccid, hypokinetic, ataxic and two mixed (ALS and Wilson-syndrome) groups, as it distinguished the flaccid and the two mixed groups from the rest.

3.5. Nasal resonance

Nasal resonance abnormalities include hypernasality and nasal emission. Nasality is caused by the dysfunction of the velopharyngeal valve, resulting in unwanted resonance in the nasal cavity. Its presence can complicate acoustic analysis, as it has several complex effects on the acoustic signal. It can be best described with some combination of five characteristics affecting vowels: (1) increase in formant bandwidth, (2), decrease in overall energy of the vowel,

(3) presence of a low-frequency nasal formant (250–500 Hz for adult males), (4) slight increase of the F1 frequency and lowering of the F2 and F3 frequencies, (5) the presence of one or more antiformants (Kent & Read, 2002). Nasal emission is caused by airflow escaping through the nasal cavity, noise arising. It is most apparent during the production of voiceless consonants. It manifests acoustically as broadband noise (Rollins & Oren, 2020) and as quasiperiodic noise (Zajac, 2021).

Castillo-Guerra (2009) compared six types of dysarthria (flaccid, spastic, ataxic, hyperkinetic, hypokinetic, mixed; all English speakers) based on twelve acoustic dimensions. One of the features that proved to be the most useful for classification was hypernasality.

3.6. Changes in voice quality

Voice quality or phonation is tied to glottal function. Its impairment can have diverse effects on speech, which can make its analysis challenging (Kent et al., 1999). Here, we discuss two types of voice abnormality for the sake of brevity: harshness and breathiness. In the case of harshness, the intensity of the fundamental frequency is prominent compared to the harmonics. Additionally, cepstral peak prominence values are lower in harsh voice than in normal voice (Heman-Ackah et al., 2014). Breathy voice is caused by insufficient glottal closure, excess airflow escaping through it. It has complex effects on the acoustic signal: higher amplitude of the first harmonic, high frequency noise, higher proportion of high-frequency energy (Hillenbrand et al., 1994).

In Fougeron et al. (2022), the voice quality score is the main contributor in the classification of the mixed types (ALS and Wilson-syndrome), as well as in many of the two-class classifications, such as hypokinetic (in PD) vs. mixed (ALS) dysarthria. Castillo-Guerra (2009) found that breathiness was one of the most relevant features when comparing five types of dysarthria. Interestingly, the results assigned no relevance to harshness, which is one of the most important features in the traditional approach.

Table 1 summarizes the most relevant distinctive features of the six types of dysarthria along their main acoustic manifestations.

4. Summary and future work

The current paper intended to give an overview of the main types of dysarthria, including the different underlying causes, some disordered speech characteristics arising from those impairments, as well as the corresponding acoustic parameters, and some possible methods to measure the most relevant acoustic features. Since the properties of the acoustic signal are connected to the manner of articulation, which is dependent on the neuromuscular system, the precise description of acoustic features of dysarthric speech could provide valuable information that could aid localization and differential diagnosis.

Six main groups of acoustic parameters were identified that could help distinguish between the types of dysarthria. The acoustic profiles of the types are not based on individual features, but rather on patterns described by the combination of several features. That is why the simultaneous analysis of multiple dimensions is needed in order to describe the types of dysarthria and identify the combination of features most relevant in terms of distinguishment. We see that temporal characteristics are examined the most extensively, however, we argue that other characteristics deserve attention as well, as they might provide important clues to the description and classification of each type, as well as the localization of impairment. Future work is needed to test the validity of said groups of acoustic parameters and to find the most informative features.

Acknowledgements

Supported by the ÚNKP-23-3-SZTE-52 New National Excellence Program of the Ministry for Culture and Innovation from the source of the National Research, Development and Innovation Fund.

Dysarthria type	Speech characteristics	Acoustic manifestation
Flaccid	breathy voice	high amplitude H1, high frequency noise
	nasal emission	broadband noise, quasiperiodic noise
	short phrases	short duration
	hypernasality	nasal formant, antiformant
	irregular AMR	variable syllable duration
Spastic	slow speech rate	longer phoneme and pause intervals
	pitch break	silent interval within the F0 contour
	slow and regular AMR	long syllable duration, low standard deviation between them
Ataxic	excess and equal stress	increased and monotonous F0 or increased intensity
	imprecise vowels	abnormal formant structures
	loudness variability	changes in intensity
	irregular AMR	variable syllable durations
Hypokinetic	monopitch	flat F0 contour
	monoloudness	monotonous intensity
	reduced loudness and stress	low intensity and F0
	fast speech rate	short intervals
	unnecessary pauses	silence
Hyperkinetic	prolonged intervals	intervals longer than normal
	breathy voice	high amplitude H1, high frequency noise
	hypernasality	nasal formant, antiformant
	tremor	F0 tremor
	slow and irregular AMR	long syllable duration, high standard deviation between them
UUMN	slow speech rate	longer phoneme and pause intervals
	imprecise articulation	varied (e.g. abnormal formant structures, irregular F2 slopes)
	harsh voice	low CPP
	reduced loudness	low intensity

Table 1: Distinguishing speech characteristics of the main types of dysarthria and their acoustic manifestations (H1: first harmonic, AMR: alternating motion rate, F0: fundamental frequency, UUMN: unilateral upper motor neuron, F2: second formant, CPP: cepstral peak prominence).

References

Ackermann, H., Hertrich, I., & Ziegler, W. (2010). Dysarthria. In J. S. Damico, N. Müller, & M. J. Ball (Eds.), *The Handbook of Language and Speech Disorders* (pp. 362–390). Chichester, West Sussex: Wiley-Blackwell.

Ball, M. (Ed.) (2021). *Manual of Clinical Phonetics*. London: Routledge.

Ball, M., & Lowry, O. (2001). *Methods in Clinical Phonetics*. London: Whurr Publishers.

Boersma, P., & Weenink, D. (2023). Praat: doing phonetics by computer [computer program. *Version*, *6*. URL: http://www.praat.org/. Retrieved 3 June 2023.

Castillo-Guerra, E. (2009). Acoustic study of dysarthria. *International Journal of Biomedical Engineering and Technology*, *2*, 352–369.

Cummings, L. (2008). *Clinical Linguistics*. Edinburgh: Edinburgh University Press.

Darley, F. L., Aronson, A. E., & Brown, J. R. (1969a). Clusters of deviant speech dimensions in the dysarthrias. *Journal of Speech and Hearing Research*, *12*, 462–496.

Darley, F. L., Aronson, A. E., & Brown, J. R. (1969b). Differential diagnostic patterns of dysarthria. *Journal of Speech and Hearing Research*, *12*, 246–69.

Duffy, J. R. (2013). *Motor Speech Disorders: Substrates, Differential Diagnosis, and Management*. St. Louis, MO: Elsevier.

Duffy, J. R., & Folger, W. N. (1996). Dysarthria associated with unilateral central nervous system lesions: A retrospective study. *Journal of Medical Speech-Language Pathology*, *4*, 57–70.

Fougeron, C., Kodrasi, I., & Laganaro, M. (2022). Differentiation of motor speech disorders through the seven deviance scores from MonPaGe-2.0.s. *Brain Sciences*, *12*, 1471–1487.

Gósy, M. (2004). *Fonetika, a beszéd tudománya [Phonetics, The Science of Speech]*. Budapest: Osiris.

Heman-Ackah, Y. D., Sataloff, R. T., Laureyns, G., Lurie, D., Michael, D. D., Heuer, R., Rubin, A., Eller, R., Chandran, S., Abaza, M., Lyons, K., Divi, V., Lott, J., Johnson, J., & Hillenbrand, J. (2014). Quantifying the cepstral peak prominence, a measure of dysphonia. *Journal of Voice*, *28*, 783–788.

Hillenbrand, J., Cleveland, R. A., & Erickson, R. L. (1994). Acoustic correlates of breathy vocal quality. *Journal of Speech and Hearing Research*, *37*, 769–778.

Juste, F. S., Rondon, S., Sassi, F. C., Ritto, A. P., Colalto, C. A., & Andrade, C. R. (2012). Acoustic analyses of diadochokinesis in fluent and stuttering children. *Clinics*, *67*, 409–414.

Kent, R. D., & Read, C. (2002). *The Acoustic Analysis of Speech*. Albany, NY: Thomson Learning.

Kent, R. D., Weismer, G., Kent, J. F., Vorperian, H. K., & Duffy, J. R. (1999). Acoustic studies of dysarthric speech: Methods, progress, and potential. *Journal of Communication Disorders*, *32*, 141–180.

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*, 417–429.

Kis, O., Tóth, A., Jakab, K., & Klivényi, P. (2020). A beszédsebesség vizsgálata Parkinson-kór-, sclerosis multiplex, valamint stroke-eredetű dysarthriák esetében [examining speech rate in dysarthria caused by parkinson's disease, sclerosis multiplex, and stroke]. *Rehabilitáció*, *30*, 3–10.

Laforce, R., Jr., & Doyon, J. (2001). Distinct contribution of the striatum and cerebellum to motor learning. *Brain and Cognition*, *45*, 189–211.

Lansford, K. L., & Liss, J. M. (2014). Vowel acoustics in dysarthria: Speech disorder diagnosis and classification. *Journal of Speech, Language, and Hearing Research*, *57*, 57–67.

Liss, J. M., White, L., Mattys, S. L., Lansford, K., Lotto, A. J., Spitzer, S. M., & Caviness, J. N. (2009). Quantifying speech rhythm abnormalities in the dysarthrias. *Journal of Speech, Language, and Hearing Research*, *52*, 1334–1352.

Lowit, A., & Kuschmann, A. (2012). Characterizing intonation deficit in motor speech disorders: An autosegmental-metrical analysis of spontaneous speech in hypokinetic dysarthria, ataxic dysarthria, and foreign accent syndrome. *Journal of Speech, Language, and Hearing Research*, *55*, 1472–1484.

Nishio, M., & Niimi, S. (2001). Speaking rate and its components in dysarthric speakers. *Clinical Linguistics and Phonetics*, *15*, 309–317.

Rollins, M., & Oren, L. (2020). Effects of nasal emission and microphone placement on nasalance score during /s/. *Proceedings of meetings on acoustics Acoustical Society of America*, *42*, 060001.

Thoppil, M., Kumar, C., Kumar, A., & Amose, J. (2017). Speech signal analysis and pattern recognition in diagnosis of dysarthria. *Annals of Indian Academy of Neurology*, *20*, 352– 357.

Zajac, D. J. (2021). Speech aerometry. In M. J. Ball (Ed.), *Manual of Clinical Phonetics* (pp. 264–281). London: Routledge.