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ACOUSTIC ANALYSIS OF VOICE IN PATIENTS WITH MULTIPLE SCLEROSISANALYSE ACOUSTIQUE DE LA VOIX CHEZ LES PATIENTS ATTEINTS DE LA SCLEROSE EN PLAQUES

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Abstract
Multiple Sclerosis (MS) is a chronic, degenerative neurological disease that affects the central nervous system (CNS), significantly influencing motor, sensory, cognitive, and linguistic functions. This study explores the utility of objective methods such as acoustic analysis, specifically using Praat software, for identifying voice disorders in individuals with multiple sclerosis. The research examines the acoustic characteristics of voices among those diagnosed with MS and assesses the prevalence of voice disorders in this group. Our sample included 8 participants, consisting of 6 MS patients and 2 healthy controls, and focused on comparing a range of vocal parameters: fundamental frequency (F0), sound pressure level (SPL), jitter, shimmer, harmonics-to-noise ratio (NHR), maximum phonation time (TMF), and voice breaks (V, B). Findings reveal that 50% of the MS patients displayed voice disorders through acoustic evaluation, suggesting that Praat software is an effective tool for ongoing monitoring of voice changes in MS patients throughout their diagnosis and treatment.
Keywords: Multiple Sclerosis, Voice Disorders, Acoustic Analysis, Praat Software.

Introduction:

Multiple sclerosis stands as a prevalent neurological disorder, marked by its chronic inflammatory and degenerative nature, and classified as an autoimmune disease. In this condition, the immune system erroneously attacks the central nervous system, specifically targeting the myelin sheath, the protective layer surrounding nerve fibers. This attack leads to significant degradation of white matter. Predominantly affecting young adults, the onset of MS typically occurs between 20 and 40 years of age, with a noted higher frequency in females.

MS patients commonly experience a range of symptoms including motor, sensory, cognitive, and linguistic impairments (Brassat, 2010; Brochet, Sèze, &Lebrune-Frenay, 2017). Among these, voice disorders and other speech-related issues such as speech breathing, resonance, and swallowing difficulties, collectively known as dysarthria, a motor speech disorder stemming from neurological impairment, are notably prevalent.

Approximately 40% of MS patients are affected by such communication disorders (Dogan, Almaz Yazici, Kocak, &Günal, 2007; Fazeli, Moradi, Soltani, Majdinasab, & Mahmoud Latifi, 2020). Utilizing non-surgical acoustic analysis to assess dysarthria offers valuable clinical insights for otolaryngologists, neurologists, and speech pathologists. It aids in the early diagnosis and differential assessment of the disease, as well as in documenting its progression (Feijó, Parente, Behlau, Haussen, & Martignago, 2004).

Moreover, analyzing vocal metrics can provide a deeper understanding of the physiological and neurological underpinnings of MS, linking specific lesion sites to unique vocal alterations such as voice weakness, thereby enhancing our comprehension of the disease’s impact on vocal function (Fazeli, Moradi, Soltani, Majdinasab, & Mahmoud Latifi, 2020).

A comprehensive array of methodologies such as perceptual, acoustic, aerodynamic, and physiological assessments are employed to evaluate voice disorders. Each of these methods necessitates the use of advanced computer technology and meticulous laboratory techniques. Among these, the acoustic evaluation is particularly notable for its quantitative and objective nature. This method facilitates a thorough analysis of speech disorders by performing spectral analysis on concrete speech data, including pitch, intensity, and vocal quality.

Such detailed examination provides a deeper understanding of the pathologies of vocal signals, uncovering aspects that might remain undetected through mere subjective auditory evaluations alone. These insights are crucial for advancing our understanding of speech-related pathologies (FERRAT, 2015; Fazeli, Moradi, Soltani, Majdinasab, & Mahmoud Latifi, 2020).

The primary goal of this research is to investigate the prevalence and specific characteristics of voice disorders in patients with multiple sclerosis. This is achieved by comparing several vocal parameters, fundamental frequency (F0), sound pressure level (SPL), jitter, shimmer, harmonics-to-noise ratio (NHR), maximum phonation time (TMF), and voice breaks (VB), between patients diagnosed with multiple sclerosis and a control group comprising healthy individuals.

Thus, we pose the following question: Do patients with multiple sclerosis experience voice disorders as determined through objective acoustic analysis?

1. LITERATURE REVIEW:

A. Feijó et al. (2004) Study:

This study undertook a physical analysis of voice in individuals diagnosed with multiple sclerosis to identify and compare the presence of voice disorders. The study comprised 106 participants, including 30 individuals with multiple sclerosis and 76 healthy controls. Exclusion criteria were set to omit individuals with prior voice disorders, those who had undergone recent laryngeal surgeries, those with respiratory diseases, and other neurological conditions.

The findings indicated that 70% of the multiple sclerosis patients and 33% of the healthy controls exhibited voice disorders. A particularly significant observation was the deviation in fundamental frequency, which was markedly higher in multiple sclerosis patients, especially women, and the increase in jitter was more pronounced in men compared to other groups. These results suggest a complex interaction between multiple sclerosis and gender influencing vocal irregularities.

B. Dogan et al. (2006) Study:

This study centered on the self-assessment and objective evaluation of voice quality in individuals with multiple sclerosis. It involved 27 patients with multiple sclerosis and 27 healthy controls matched by age and gender. The methodological approach included video laryngostomy and physical voice analysis using MdVP software, supplemented by self-assessment tools such as GRBAS and the Voice Handicap Index (VHI30).

The outcomes revealed that jitter, shimmer, and weak voice indices were significantly higher in the multiple sclerosis group, with maximum phonation times being notably shorter. Although the noise-to-harmonics ratio and average fundamental frequency showed no significant differences between the two groups, the study highlighted significant impairments in voice quality among the multiple sclerosis patients.

This deterioration in voice parameters, including fundamental frequency, weak voice index, and jitter values, collectively contributes to the observed poorer voice quality in this patient cohort (Dogan, Almaz Yazici, Kocak, &Günal, 2007).

C. Duranovic et al. (2011) Study:

The research conducted by Duranovic et al. focused on delineating the voice characteristics of individuals diagnosed with multiple sclerosis and comparing these findings with a control group. The study's participant pool included 17 individuals, both male and female, aged between 27 and 55 years.

A corresponding control group was comprised of 17 age and gender-matched individuals. Analysis centered on the continuous vocalization of the vowel /a/ utilizing the Multi-Dimensional Voice Program (MDVP). The findings highlighted significant variances in voice characteristics between the multiple sclerosis group and the control group.

Notable differences were observed in several parameters, including the standard deviation of the fundamental frequency, jitter, amplitude variation, irregular vibrato degree, and the noise-to-harmonics ratio, as well as variables associated with the amplitude tremor index. The study demonstrated the efficacy of the MDVP tool in monitoring changes in voice characteristics of multiple sclerosis patients throughout the diagnostic and treatment phases (Duranovic, Ibrahimagic, &Toromanovic, 2011).

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D. Bauer et al. (2013) Study:

This investigation aimed to assess both self-reported and perceptually analyzed voice quality and its correlation with neurological dysfunction in multiple sclerosis patients. The study employed two key assessment tools: the Voice Handicap Index (VHI) and the voice-related quality of life questionnaire, alongside perceptual voice evaluation using the GRBAS scale. These assessments were compared with the neurological assessments scored via the Expanded Disability Status Scale (EDSS).

The participant group included 36 patients with multiple sclerosis and 32 healthy individuals without voice or neurological symptoms. Results indicated that a significant proportion of multiple sclerosis patients reported voice issues, though no substantial correlation was found between the severity of voice disorders and the EDSS scores, with the exception of the 'weakness' element on the GRBAS scale. This finding suggests a nuanced relationship between perceived voice issues and actual neurological impairment (Bauer, Aleric, Jancic, Knezevic, Prpic, &Kacavenda, 2013).

E. Patrizia et al. (2017) Study:

This study focused on analyzing vocal signals from multiple sclerosis patients to identify relevant patterns that could aid in diagnosis and monitoring. The study recruited 53 multiple sclerosis patients from the Neurosurgical Unit, Multiple Sclerosis Center in Cosenza, Italy. The cohort was divided into 18 patients with primary multiple sclerosis (7 men and 11 women) and 35 with relapsing multiple sclerosis (11 men and 24 women), alongside a control group of healthy individuals aged between 24 and 68. Vocal assessments involved the continuous and sustained pronunciation of the vowels /a/, /e/, /i/, /o/, /u/ over 5 seconds, which were analyzed using the PRAAT software.

The research applied two analytical methods: vocal analysis and vowel metrics, to compare the vocal signals from multiple sclerosis patients with those from healthy individuals. Results from both methods were presented, followed by a statistical analysis to determine the most significant findings. This detailed analysis yielded patterns that may serve as vital indicators for physicians in the early diagnosis and ongoing monitoring of multiple sclerosis, thus potentially enhancing patient quality of life (Patrizia, Domenico, Giuseppe, Redavide, &BrunoBossio, 2017).

2. CONCEPTUAL ASPECT:

2.1 Multiple Sclerosis:

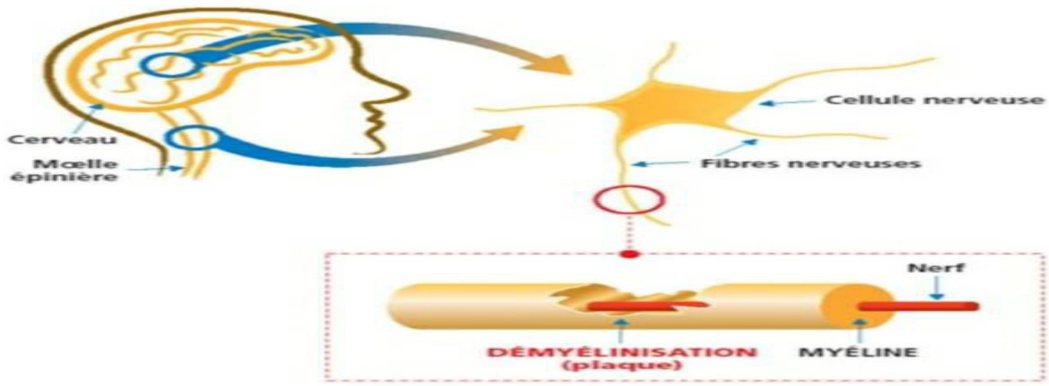
- **Definition**:

Historically, Multiple sclerosis (MS) is defined as a chronic inflammatory disease that predominantly affects the central nervous system (CNS), leading to prominent focal lesions in the brain and spinal cord's white matter. These lesions are characterized by primary demyelination and variable degrees of axonal loss (Charcot, 1880).

As described by Bruno Brochet et al. (2017), "Multiple sclerosis is a chronic inflammatory and degenerative neurological disease. It is an autoimmune disorder where the immune system attacks the myelin sheath enveloping the nerves. This condition targets the central nervous system, including the brain and spinal cord, and is marked by demyelinated inflammatory patches in both white and gray matter.

The degradation of the myelin sheath interrupts the transmission of nerve signals, potentially leading to nerve damage. This disruption manifests as patches in the central nervous system observable in scans" (Bruno Brochet, Sèze, &Lebrune-Frenay, 2017).

Figure 1: Physiological Pathology of Multiple Sclerosis



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- **Progressive Forms of Multiple Sclerosis**:

The disease is categorized based on its progression and occurrence of relapses:

A. **Relapsing-Remitting MS (RRMS)**:

This form is the most commonly observed at onset, affecting over 75% of cases. Initially, periods of relapses are followed by recovery phases, where symptoms may disappear or leave residuals.

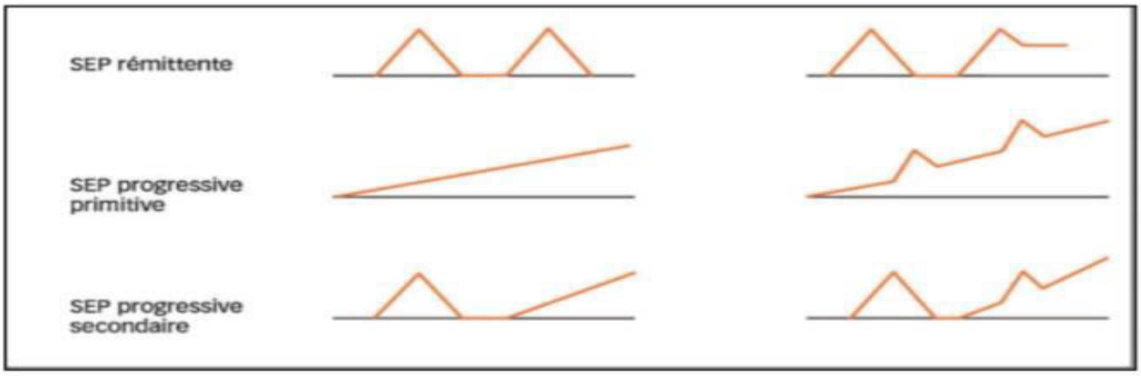
B. **Secondary Progressive MS (SPMS)**:

Transitioning from RRMS, approximately 50% of patients experience this progression after 15 to 20 years, where symptoms worsen gradually and persist without full recovery.

C. **Primary Progressive MS (PPMS)**:

Characterized by a steady progression of symptoms from the outset, without distinct relapses but may include periods of stability (Brochet, Gilles, & Jean, 2005).

Figure 2: Progressive Forms of Multiple Sclerosis



- **Symptoms**:

Symptoms of MS are diverse, affecting various functions of the central nervous system, with considerable variability among individuals. As noted by Brochet, "It is a condition that might encapsulate the most extensive variety of neurological symptoms in a single individual, marked by a spectrum of lesion multiplicities, a diversity of progression forms, and significant inter-individual differences" (Brochet, Gilles, & Jean, 2005).

The researchers identified the most common symptoms in patients with multiple sclerosis in its chronic stage:

_ **Motor Symptoms**: Occur in 80% to 90% of patients, including paralysis, limb weakness, coordination disorders, and impairments in voluntary control, particularly affecting facial and oral movements.

_ **Visual Symptoms**: Experienced by 70% to 80% of patients, predominantly due to optic neuritis, manifesting as full or partial vision loss accompanied by pain, blurring, and diminished color perception and visual field during relapses.

_ **Sensory Symptoms**: Present in 70-80% of patients, these symptoms are highly subjective and vary widely, typically including sensations like tingling, numbness, and pins and needles.

_ **Urinary and Bowel Disorders**: Found in 80-90% of patients, these symptoms significantly impact social interaction and overall quality of life.

_ **Chronic Fatigue**: Affects about one-third of patients from the early stages, manifesting as physical or mental exhaustion during activities or even at rest, often severely limiting patient capabilities despite minimal neurological impairment.

_ **Pain in Multiple Sclerosis (MS) Patients:** Pain, experienced by 63% of multiple sclerosis patients, is often highly debilitating. The etiology of this pain is multifaceted, encompassing central neuropathy, optic neuritis, postural issues stemming from immobility, muscle spasms, headaches, and side effects from treatments. Given its diverse origins, comprehensive and specialized care is essential to manage these symptoms effectively.

_ **Cognitive Impairments Associated with Multiple Sclerosis:** Cognitive impairments, affecting 30% to 70% of patients, manifest early in multiple sclerosis and tend to be more pronounced in its progressive forms. These impairments predominantly hinder the processing speed of information and phonological memory. Additionally, they adversely affect working memory, attention, executive functions, and longterm memory storage. The severity of these cognitive symptoms varies widely among individuals. Over time, as the disease progresses to a chronic stage, these impairments may lead to a cumulative disability, resulting in significant social isolation. (Brassat, 2010)

2.2 PRAAT® Software – A Tool for Acoustic Analysis:

PRAAT® is an advanced software crafted for acoustic and speech analysis, developed by Paul Boersma and David Weenink at the Institute of Phonetic Sciences, University of Amsterdam. This software, which is regularly updated and freely accessible at http://www.praat.org, supports a plethora of functionalities, including spectral analysis, synthesis, and the application of neural networks.

It is particularly valued for its ability to capture a broad spectrum of vocal information such as voice formants, spectra, intensity, pitch, and more, making it an indispensable tool for phoneticians. Its application extends to speech therapy clinics, where it plays a critical role. (Pascal van Lieshout, 2006; VOIX, 2013)

2.3Physical Analysis of Voice:

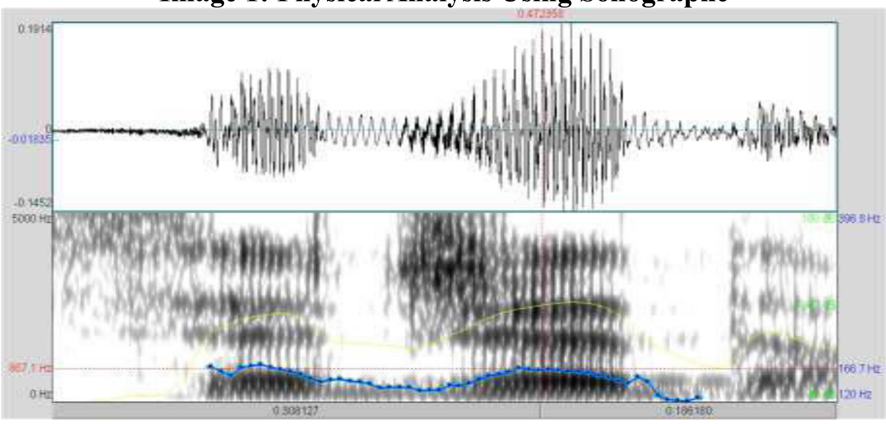
Defined by CORPELET as a "vocal pulse arising from the vibration of the vocal cords that propagates through exhaled air to produce a natural frequency (fundamental frequency), which is subsequently modulated by resonance cavities," the voice is characterized by its intensity, frequency, and timbre. (D and M, 1990)

The principal aim of physical speech analysis is to isolate and quantify those physical components that most accurately reflect the physiological processes underlying speech production. In diagnosing speech disorders, this analysis is invaluable, providing speech pathologists with detailed, measurable data (e.g., pitch, intensity, vocal quality) to objectively evaluate speech anomalies. Spectral analysis, facilitated by tools like the Sonographe spectrometer, enhances the understanding of vocal signal pathologies that may not be easily detectable through standard patient assessments.

Spectral analysis measures the frequency content of a vocal signal, according to its energy distribution, using mathematical processing. It facilitates breaking down the very complex speech signal into a sum of simpler elements, thus identifying vocal parameters. There are several computational modes for speech analysis.

Typically, the software employs the Fourier transform, a fast computational algorithm, which analyzes the sinusoidal components of the signal. Often referred to by its acronym FFT (Fast Fourier Transform), it facilitates the transition from the time form of the signal to its frequency form and vice versa. Additionally, LPC processing (Linear Predictive Coding), a technique for low-bitrate speech encoding, is also utilized. (Etienne Sicard and Anne, 2021)

Image 1: Physical Analysis Using Sonographe



- **Physical Characteristics of Voice and Its Pathological Parameters:**

2.4 Voice Height: Fundamental Frequency (F0):

This is defined by the number of vibration cycles (opening and closing) per second of the vocal cords, expressed in hertz (Hz). It corresponds to pitch and enables the production of low or high sounds, varying with the length, thickness, and tension of the vocal cords. The frequency increases when the pressure under the glottis rises and the larynx ascends in the neck, leading to a shortening of the pharyngeal dimensions, which results in an increase in the tension and length of the vocal cords.

It is measured using computer software. Glaze (1988) showed that the fundamental frequency decreases with age. Typically, this fundamental frequency ranges from 90 to 110 Hz in men's spoken voice and from 200 to

220 Hz in women's. Acoustically, pitch is known by the fundamental frequency, where the periodic convergence and divergence of the vocal cords determine the pitch. This is referred to as the "vibratory cycle" of the vocal cords.

The higher the number of vibrations per second, the sharper the sound; the fewer the vibrations, the deeper the sound. The pitch is related to the mechanical mechanism of the vocal cords; the degree of tension and elasticity of the vocal cords affects the pitch. The measure of fundamental frequency disturbance is expressed as JITTER.

2.5 JITTER: A Measure of Fundamental Frequency Disturbance:

JITTER is a measure of disturbances in the fundamental frequency of the vocal signal. This reflects variations in the duration between one or several cycles. JITTER denotes vocal disturbance arising from neurological, aerodynamic, or biomechanical dysfunction. Using PRAAT® software in this research, we only mention definitions and the normal thresholds in this software.

In Praat, there are five different measurements of JITTER. For simplicity, we will present that the pathological threshold for JITTER (local) is "the average difference between two successive vibratory cycles of the larynx relative to the average period of the signal." Thus, the result is expressed as a percentage.

According to the Praat manual, the normal/pathological threshold is set at 1.04%. To better understand that the voice is vibration, consider the following example: Suppose the fundamental frequency of the voice is 150 Hz, which means we have 150 vibratory cycles of the larynx. (Bedouet, 2020) (VOIX, 2013) According to Patrizia Vizza, a pathological voice represents a higher percentage of vibration compared to a healthy voice: A variation between 0.5% and 1% is considered significant.

2.6 Timbre:

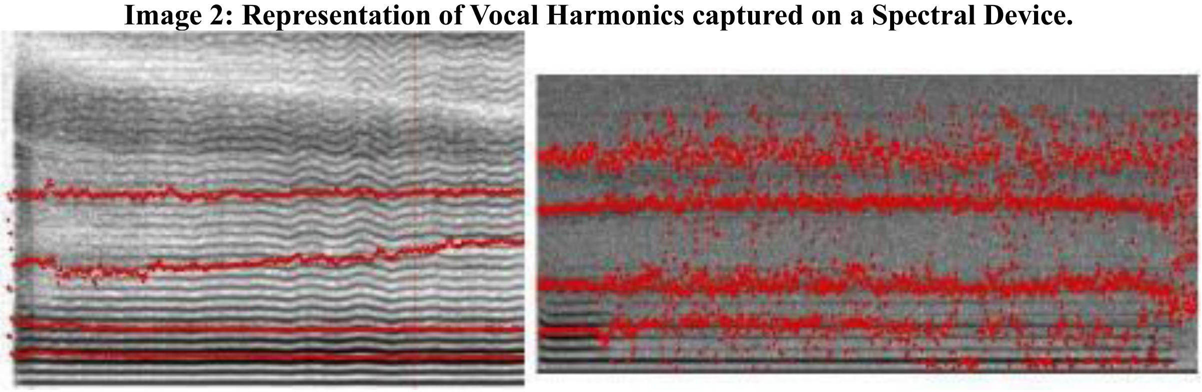
Timbre, alternatively known as the tone color of a voice, is characterized by the richness of the harmonic overtones. These harmonics, which are integral multiples of the fundamental frequency, originate through resonance mechanisms. Each individual has a unique timbre that allows for the recognition of a person's voice over the telephone based solely on its quality. Similarly, the same musical note, when executed on different instruments at the same pitches and volumes, produces sounds that are distinctively characteristic due to variations in timbre.

2.7 Harmonics to Noise Ratio: A Measure of Timbre Disturbance

The harmonics to noise ratio is a critical metric for assessing timbre disturbance. Harmonic overtones, originating from semi-periodic disruptions in airflow between the vocal cords, contrast with "inter-harmonics," which are produced from turbulent, continuous airflow through the glottis opening. As such, "intra-harmonics" are akin to components of noise.

Deterioration in laryngeal function and a decrease in the efficiency of the larynx lead to less precise adjustments of the vocal folds to the airflow. Consequently, the energy that was once manifested as harmonics increasingly transitions to noise within the spectral graph, signaling a shift from clear tonal sounds to more disturbed, noisy outputs. (Bedouet, 2020) (Kamal, 2020) (VOIX, 2013)

Image 2: Representation of Vocal Harmonics captured on a Spectral Device.



2.8 Sound Intensity:

Sound intensity is directly linked to acoustic power and denotes the acoustic energy captured per unit of time and per unit surface area. As acoustic power is emitted from a sound source, it disperses throughout the surrounding space, and its intensity diminishes as the distance from the source increases. This phenomenon was quantified by Alexander Graham Bell who introduced the Bel scale, with the decibel (dB) serving as its subunit.

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The decibel is a logarithmic unit designed to mirror the auditory capabilities of the human ear. The variations in sound intensity over time are thoroughly assessed using a sonogram. In audiological terms, there are subjective and objective assessments of sound: "loudness" pertains to the perception of intensity, whereas "intensity" itself is a measure of sound power. Importantly, the ear's sensitivity varies with frequency, for example, a sound at 50 decibels is perceived more intensely at 1000 Hz compared to at 100 Hz.

2.9 SHIMMER: A Measure of Amplitude Disturbance

SHIMMER is an analytical measure used to quantify short-term fluctuations in the amplitude of the fundamental frequency. There are various methods to calculate SHIMMER, but this explanation adheres to the methodologies preferred by the creators of PRAAT®. This technique involves calculating the average differences in maximum amplitude between two consecutive periods and dividing this by the average maximum amplitude of each period. SHIMMER effectively measures the irregularity in the intensity of vibration cycles, presenting this irregularity as a percentage. The standard or pathological threshold for SHIMMER is set at 3.81%.

To illustrate, if the fundamental frequency stabilizes at 150 Hz and the average difference between the maximum amplitudes of consecutive periods is 3 decibels, with an average maximum amplitude per period of 70 decibels, then SHIMMER is calculated as 3/70 decibels = 0.04285714, which is then multiplied by 100 to result in a percentage of 4.28%. This percentage clinically classifies the voice as pathological when assessed against the established threshold. (Bedouet, 2020) (VOIX, 2013)

3. PRACTICAL ASPECT:

3.1 Methodology:

We adopted a descriptive case study approach, based on a sample of 8 individuals, 6 of whom are diagnosed with multiple sclerosis (5 women and 1 man) and 2 reference cases (1 woman and 1 man) who do not suffer from any disease or voice disorders. We conducted voice recordings of all sample members through vocal tasks: producing the vowel /a/ with good sound quality and at a high volume for as long as possible, then analyzed using Praat software.

The acoustic characteristics studied were: Fundamental Frequency (F0), Sound Pressure Level (SPL), Jitter (irregularity in the fundamental frequency), Shimmer (irregularity in sound intensity), Noise-to-Harmonic Ratio (NHR), Maximum Phonation Time (TMF), and Voice Breaks (VB).

3.2 Study Location:

The study was conducted at the Institutional Hospital for Functional Rehabilitation Ras El Ma, Sétif Province.

3.3 Study Tools:

BY-M1 microphone, computer, Praat software.

3.4 Praat Settings:

Spectrogram settings: View range 0-5000Hz, Window length 0.03sec, Dynamic range 70dB.

3.5 Case Presentations:

Table 1: Reference Cases:

Case	Gender	Age
A	Female	35
B	Male	38

Table 2: Patient Cases:

Case	Gender	Age	Onset Year	Phoniatric Care	Voice Disorder Complaints
Case 1: A.K	Female	51	2006	None	None
Case 2: S.S	Female	48	2005	None	None
Case 3: M.H	Male	38	2012	None	None
Case 4: M.A	Female	36	2016	None	Complains
Case 5: M.Y	Female	42	2006	None	Complains
Case 6: H.A	Female	38	2010	None	Complains

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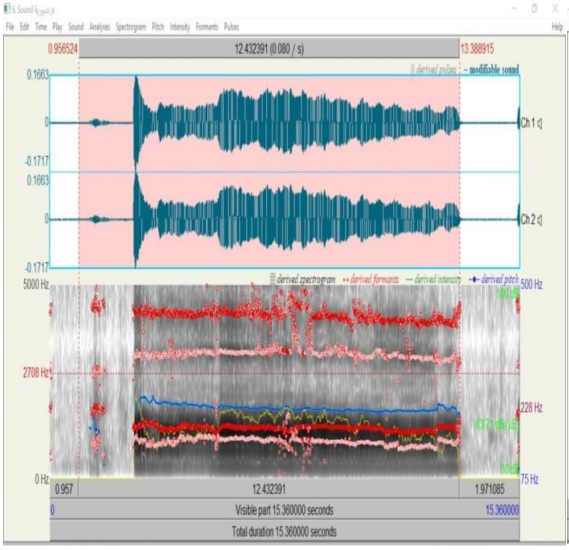
4. RESULTS DISPLAY:

4.1 Spectral Representation of Physical Characteristics of the Vowel /a/ in Multiple Sclerosis Patients

Image 3: Case 1Image 4: Case 2



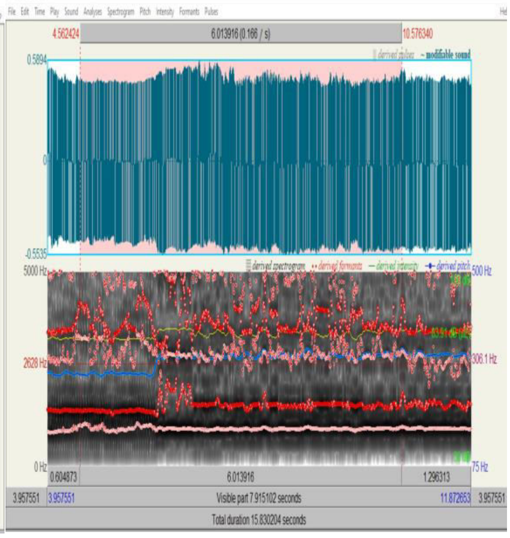
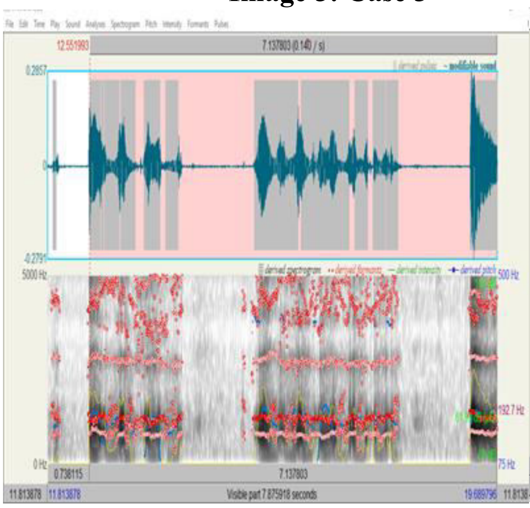


Image 5: Case 3 **Image 6: Case 4**



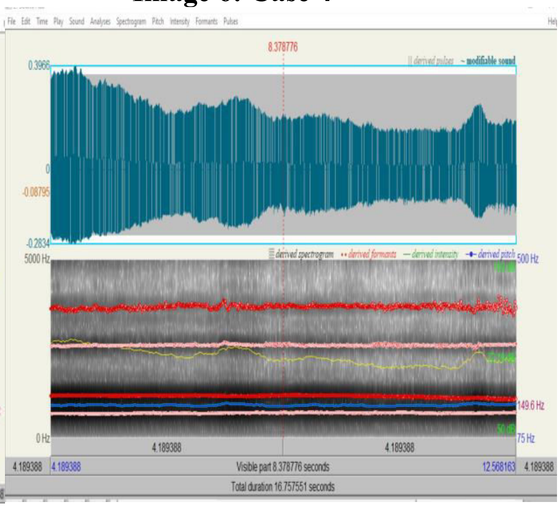
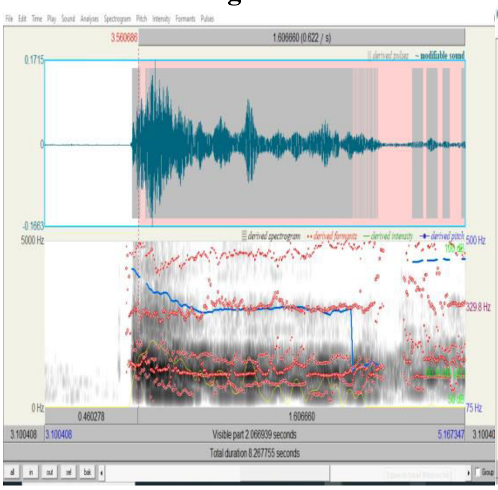
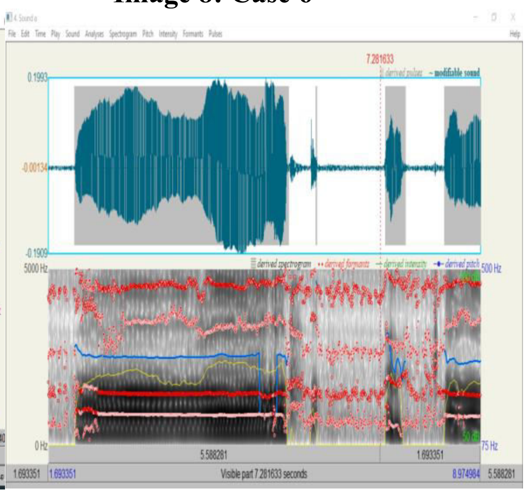


Image 7: Case 5 **Image 8: Case 6**





4.2 Displayed Acoustic Characteristics:

Table 3: Reference Cases:

Case	F0 (Hz)	SPL (dB)	Jitter (%)	Shimmer (%)	NHR (dB)	Voice Break	TMF (s)
Healthy Case A	326	84.37	0.26	1.61	29	0	20
Healthy Case A	148	75	0.39	1.25	30.64	0	18

Table 4: Multiple Sclerosis Patients:

Case	F0 (Hz)	SPL (dB)	Jitter (%)	Shimmer (%)	NHR (dB)	Voice Break	TMF (s)
1	331	82.8	0.62	1.60	26.39	0	15
2	262	63.7	0.55	3.41	22	3	12
3	151	71.3	0.22	1.64	23	0	16
4	176	61.5	2.87	13.74	7.52	14	8
5	297	60	0.81	6.22	16	3	3.23
6	325	50.19	2.1	17.65	9.31	7	8

5. RESULTS ANALYSIS:

5.1 Case 1:

- **Fundamental Frequency:** The recording showed 331 Hz, slightly higher than healthy standards but within normal range.
- **Intensity:** Recorded at 82.8 dB, which is a normal value compared to healthy standards.
- **Jitter:** Recorded at 0.62%, which is a normal value.
- **Shimmer:** Recorded at 1.60%, which is a normal value.
- **Harmonics:** Recorded at 26 dB, normal compared to healthy standards.
- **Voice Breaks:** None were found.
- **Duration:** 15 seconds, which is normal.

5.2 Case 2:

- **Fundamental Frequency:** Recorded at 262 Hz, lower than healthy Case A but within the normal range.
- **Intensity:** Recorded at 63.7 dB, which is low compared to healthy Case A and the standard value.
- **Jitter:** Recorded at 0.55%, which is a normal value.
- **Shimmer:** Recorded at 3.41%, higher than healthy Case A but within the normal range.
- **Harmonics:** Recorded at 22 dB, lower than healthy Case A and the standard value.
- **Voice Breaks:** 3 breaks were found.
- **Duration:** The duration was 12 seconds, somewhat low compared to healthy Case A and the standard value.

5.3 Case 3:

- **Fundamental Frequency:** Recorded at 151 Hz, slightly higher than healthy Case B but within the normal range.
- **Intensity:** Recorded at 71 dB, which is a normal value compared to the healthy standard.
- **Jitter:** Recorded at 0.22%, which is a normal value.
- **Shimmer:** Recorded at 1.25%, which is a normal value.
- **Harmonics:** Recorded at 30 dB, normal compared to the healthy standard.
- **Voice Breaks:** None were found.
- **Duration:** 16 seconds, which is normal compared to the healthy standard.

5.4 Case 4:

- **Fundamental Frequency:** Recorded at 176 Hz, lower than healthy standards and below the normal range.

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- **Intensity:** Recorded at 61.5 dB, which is low compared to healthy standards and the normal value.
- **Jitter:** Recorded at 2.87%, which is high compared to healthy Case A and the standard value.
- **Shimmer:** Recorded at 13.8%, which is high compared to healthy Case A and the standard 5.
- **Harmonics:** Recorded at 7.52 dB, lower than healthy Case A and the standard values.
- **Voice Breaks:** 14 breaks were found, which is a very high number.
- **Duration:** The duration was 8 seconds, low compared to the normal standard.

5.5 Case 5:

- **Fundamental Frequency:** Recorded at 297 Hz, lower than healthy Case A but within the normal range.
- **Intensity:** Recorded at 60 dB, which is low compared to healthy Case A and below the standard value.
- **Jitter:** Recorded at 0.81%, which is a normal value.
- **Shimmer:** Recorded at 6.22%, higher than healthy Case A and the standard value.
- **Harmonics:** Recorded at 16 dB, lower than healthy Case A and the standard value.
- **Voice Breaks:** 3 breaks were found.
- **Duration:** The duration was 3.23 seconds, very low compared to healthy Case A and the standard value.

5.6 Case 6:

- **Fundamental Frequency:** Recorded at 325 Hz, higher than healthy Case A but within the normal range.
- **Intensity:** Recorded at 50 dB, which is low compared to healthy Case A and below the standard value.
- **Jitter:** Recorded at 2.1%, which is high compared to healthy Case A and the standard value.
- **Shimmer:** Recorded at 17.56%, which is high compared to healthy Case A and the standard value.
- **Harmonics:** Recorded at 9.3 dB, lower than healthy Case A and the standard value.
- **Voice Breaks:** 7 breaks were found.
- **Duration:** The duration was 8 seconds, low compared to healthy Case A and the standard value.

6. RESULTS DISCUSSION:

A. **Case 1:** All physical properties are normal when compared to the healthy case and standard values, except for a slight elevation in the fundamental frequency, which results in a somewhat sharper voice. There is no evidence of a voice disorder.
B. **Case 2:** This case features reduced intensity, indicating a weak voice, and a shorter duration, which may suggest respiratory weakness. However, other acoustic properties are within the normal range compared to the healthy case and standard values. This indicates a voice disorder that primarily relates to intensity and duration.
C. **Case 3:** All physical properties are within the normal range compared to the healthy case and standard values, indicating the absence of a voice disorder.
D. **Case 4:** There are disruptions in all physical properties: a reduced fundamental frequency suggests a deeper voice; low intensity indicates a weak voice; high jitter and shimmer percentages, increased noise levels, and numerous voice breaks are observed. Additionally, the short duration indicates respiratory weakness. This configuration suggests a complex voice disorder affecting multiple physical properties including frequency, intensity, respiratory function, and frequent voice breaks.
E. **Case 5:** This case displays weak intensity and disturbances in shimmer percentage, coupled with low noise levels and short duration. These characteristics suggest respiratory weakness, indicating a voice disorder characterized by weak intensity, irregular intensity patterns, numerous voice breaks, and respiratory issues.
F. **Case 6:** Low intensity suggests a weak voice; high jitter and shimmer percentages, low noise levels, and numerous voice breaks are present. The short duration again points to respiratory weakness.

This case suggests a voice disorder impacting all examined physical properties: frequency, intensity, respiratory capacity, and frequent voice breaks.

CONCLUSION:

From the analysis presented, the following conclusions are drawn:

The primary goal of physical analysis of the voice is to extract suitable indicators that help identify vocal characteristics, providing information about the state of the speaker's vocal system. In this context, several indicators have been dedicated, such as Fundamental Frequency (F0), Sound Pressure Level (SPL), Jitter (irregularity of fundamental frequency), Shimmer (irregularity of sound intensity), Noise-to-Harmonics Ratio (NHR), Maximum Phonation Time (TMF), and Voice Breaks (V, B) in patients with multiple sclerosis. It is concluded that:

- Multiple sclerosis is a neurodegenerative disease that can affect the voice as a complex phenomenon resulting from interactions between the respiratory system, larynx, and resonance. Phonation or sound production occurs when air is expelled from the lungs through the glottis, creating a pressure drop across the larynx. The vibrations of the vocal cords modulate the air pressure and flow through the larynx, and this modulated air flow is the primary component of sound.
- Our study revealed that patients with multiple sclerosis exhibited vocal disorders, with 3 out of 6 patients showing disturbances, representing 50%. This finding aligns with the study by Feijó et al. (2004), which found a 70% occurrence of voice disorders in multiple sclerosis patients compared to 33% in healthy controls, establishing a correlation between multiple sclerosis and voice disorders. Similarly, the study by Duranovic et al. (2011) showed significant differences in vocal characteristics compared to a control group, and Bauer et al. (2013) also reported numerous voice problems among patients with multiple sclerosis.
- Vocal disorders were evident through the acoustic analysis of the vowel /a/, showing disturbances in fundamental frequency (generally lowered), intensity (also lowered), irregularity in the fundamental frequency, irregularity in sound intensity, noise levels, numerous voice breaks, and weak phonation time and respiratory strength. Duranovic et al. (2011) highlighted significant differences in the vocal characteristics of multiple sclerosis patients compared to the control group in terms of standard deviation of the fundamental frequency, jitter, and variability of intensity.
- Describing vocal function and assessing voice problems are also complex tasks in multiple sclerosis. It can be stated that acoustic analysis using Praat software enhances our understanding of voice production in patients, and Praat software is a useful tool for monitoring further changes in vocal characteristics of multiple sclerosis patients during diagnostic and treatment processes.

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