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Left hemisphere lateralization in unilateral upper motor neuron dysarthria via quantitative acoustic analysis

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This paper aimed to identify specific acoustic parameters F1, F2, and Vowel Space Area (VSA), Vowel Articulation Index (VAI), Formant Centralization Ratio (FCR) for evaluating speech in Mandarin-speaking individuals with Unilateral Upper Motor Neuron (UUMN) dysarthria. Additionally, it explored the correlation between dysarthria severity and lesion side based on these parameters and scale results. This study conducted comparative study using acoustic spectral analysis to analyze phonetic features among UUMN dysarthria (UUMND) patients and neurologically normal adults, and the Left-sided and Right-sided upper motor neuron dysarthria (UMND) groups. The Mandibular-Oral Motor Function Assessment Scale (MOMFAS) was used in the study. The acoustic parameters F1, F2 and VSA, VAI, FCR showed significant differences between individuals with UUMN dysarthria and neurologically normal adults. Comparing left-sided upper motor neuron (UMN) dysarthria patients with right-sided UMN dysarthria patients, a considerable increase in FCR was observed in the left-sided group, while VSA and VAI showed significant decreases. The mean scale score of left-sided UMN dysarthria patients was also significantly lower than that of individuals with right-sided UMN dysarthria. The severity of UUMND was more pronounced in individuals with left-sided lesions, providing supportive evidence of lateralization on the left hemisphere. The acoustic indices F1, F2 and VSA, VAI, FCR can sensitively reflect the vowel changes of UUMND patients. They could be utilized not only to describe the acoustic properties of UUMND patients but also to assess the effectiveness of rehabilitation therapy on impaired vowel articulation in such patients.

Keywords Acoustic analysis, Unilateral upper motor neuron dysarthria, Stroke, Mandarin, Vowel production

Abbreviations

VSA	Vowel space area
VAI	Vowel articulation index
FCR	Formant centralization ratio
UMN	Upper motor neuron
UMND	Upper motor neuron dysarthria
UUMN	Unilateral upper motor neuron
UUMND	Unilateral upper motor neuron dysarthria
MOMFAS	Mandibular-oral motor function assessment scale

Dysarthria is classified as a 'motor speech disorder' resulting from diseases affecting the peripheral or central nervous system. The pathophysiological mechanism of dysarthria involves a series of dysfunctions, including breath, resonance, control of rhythm, and the movement of vocal organs, which ultimately leads to impaired speech[1]. Focal unilateral pyramidal tract lesions due to stroke are common and may involve the motor cortex, cell bodies, and/or axons. Such lesions produce contralateral upper motor neuron signs frequently involving the speech musculature. This condition has been clinically manifested as an abnormal oropharyngeal cavity ratio

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(the transverse-to-anteroposterior diameter ratio of the oropharyngeal cavity beyond mean ± 2SD), decreased magnitude and rate of articulatory movements, uncoordinated movements between articulators, and vowel production deficits, resulting in reduced speech intelligibility[2]. Common symptoms of UUMND include slurred articulation of consonants, distorted vowels, irregular pauses during articulation, decreased volume, and either excessive or insufficient emphasis placed on speech stress. Overall severity typically falls within the mild to moderate range.

Although dysarthria is a well-recognized symptom of stroke, there remains limited understanding of its full spectrum of clinical characteristics, severity, and anatomic specificity (including lesion location and side), particularly when it arises secondary to UUMN involvement[3]. Urban et al. found that extracerebellar infarcts causing dysarthria were consistently located along the pyramidal tract in all patients examined, affecting speech and articulation abilities[4]. In a subsequent study, they further noted that articulatory abnormalities were the predominant deviation, particularly affecting consonant production[5]. Left hemisphere lesions were associated with more severe speech and articulation impairments, regardless of the lesion's specific location. De Cock et al. reported that the majority of mild dysarthria patients showed complete recovery within one week of symptom onset[6]. The observed speech characteristics primarily reflected impairments in the articulation, phonation, and respiration subsystems. Rusz et al. found that patients with Parkinson's disease who had lower left dopamine transporter (DAT) availability exhibited higher dysarthria severity, as measured by the composite dysarthria index, compared to those with lower right DAT availability[7]. Collectively, these studies highlight that the severity of dysarthria would be closely linked to lesion location, brain damage extent, and the functional changes in specific brain regions.

Acoustic Spectral Analysis is utilized to describe and assess the severity of dysarthria by measuring relevant acoustic metrics. It is quantitative, objective, and precise for tracking the progression of the disease, evaluating recovery, and assessing the effectiveness of treatment strategies. Since vowels distortion is one of the phonetic characteristic of dysarthria, research on the pathology of dysarthria has mostly concentrated on the acoustic characterization of vowels[8]. Reduced speech intelligibility is one of the results of distortion, which is characterized by a propensity towards vowel concentration (the acoustic phenomenon where vowel formant frequencies become more centralized within the vowel space in certain speakers), and a reduction in the vocal organs' range of motion[9]. Resonance peaks are the most accurate measure of vowel quality since they largely determine the timbre or tone of vowels[10]. Vowels F1, F2, and F3 are linked to different vocal tract shapes and formant frequencies, with F1 and F2 being crucial factors in determining vowel timbre. Vowel characteristics obtained from temporal and spectral measurements were shown in earlier research to effectively differentiate dysarthria from normal speech[11].

Vowel concentration is frequently measured by VSA, which is obtained from the first and second resonance peaks of angular vowels[12]. VSA is a measure of vowel distinctiveness calculated by the triangular area of fundamental vowels /a/, /i/, and /u/ in the F1-F2 formant plane. Larger VSA indicates clearer vowel articulation. It represents the region enclosed by angular vowels in a particular language and serves as an indicator of vowel intelligibility and the precision of articulatory movements. Higher vowel concentration is correlated with a smaller VSA[13,14]. Mou and other researchers have provided evidence that individuals with dysarthria resulting from cerebral palsy (CP) showed a reduced vowel space in Mandarin Chinese compared to children with regular development[11]. Furthermore, they have established the value of the vowel spatial triangle area (tVSA) as a tool to evaluate the condition of individuals with CP dysarthria and track the effectiveness of rehabilitation interventions[11]. It should be mentioned that tVSA may not be sensitive enough to identify mild instances of dysarthria and may be affected by random variability caused by factors like word frequency, voice neighborhood density, and vocabulary.

In order to quantify the extent of vowel concentration, Sapir et al. proposed more robust and trustworthy metrics, namely the FCR and VAI[15]. FCR is an index quantifying vowel formant convergence, revealing the degree of vowel space reduction, and VAI is a comprehensive metric integrating acoustic and articulatory parameters to assess the complexity and precision of vowel production across multiple dimensions. Sapir et al. demonstrated that FCR and VAI were more sensitive than the VSA at distinguishing dysarthric speech from normal speech, with minimal influence from gender and age. Likewise, Lansford and Liss found that FCR was more strongly correlated with speech intelligibility in dysarthria than conventional VSA measures[16,17]. It was discovered that FCR-based assessments of speech intelligibility were 15% more accurate than VSA-based ones. Three vowel-focused measures, VAI, FCR, and VSA, were investigated for their stability, reliability, and sensitivity recently. The results showed that VAI had better temporal stability and sensitivity when noise interference was present[18]. The degree of vowel concentration was more recently characterized by Mou et al. using a novel acoustic-physical measure called the elliptical range of vowel discretization[19]. They analyzed and contrasted five acoustic parameters, including elliptical range and acoustic distance, for six types of unit sounds in 31 patients with post-stroke dysarthria. The findings demonstrated a significant correlation between the severity of dysarthria and the elliptical range of vowel discretization, confirming the parameter's higher sensitivity than VSA. As a result, it may be a useful tool for evaluating speech intelligibility reduction, vowel articulation impairment in stroke patients, and the effectiveness of rehabilitation therapy.

Despite the high prevalence of dysarthria in acute stroke cases, there is a substantial lack of prospective studies that have examined the relationship between dysarthria severity and lesion sites in acute stroke victims. Previous acoustic analyses were conducted retrospectively and suffered from several limitations, including small sample size, inadequate determination of lesion topography, exclusion of cases with multiple lesions, and inclusion of patients up to only 3 months post-stroke onset.

In this study, we presented data for 52 consecutive patients diagnosed with dysarthria resulting from acute unilateral cerebral infarctions. We aimed to compare F1, F2, and VSA, FCR, VAI between individuals with UUMND and a control group of healthy individuals, as well as UUMN patients with different sides of stroke (VSA, FCR, and VAI are constructed based on F1 and F2). The purpose of this paper was to explore the effectiveness of the above vowel quantitative acoustic index in the evaluation of UUMND and their association with the side of lesion, as well as the correlation between dysarthria severity and lesion side based on these parameters and the scores of MOMFAS (a scale evaluating mandible, lips, and tongue motor functions across three domains: relaxation state, oral mobility, and articulatory performance).

Methods
Participants
Fifty-two native Mandarin-speaking unilateral upper motor neuron patients with sudden onset of dysarthria due to unilateral, non-space-occupying cerebral infarction, and the absence of a history of previous stroke or transient cerebral ischemia, were included in the UUMND group. The age of the dysarthria speakers ranged from 45 to 89 years old (mean ± standard deviation (SD): 64.67 ± 9.67 years). The demographic data are shown in Table 1. There is no statistically significant difference ($P > 0.05$) in the comparison of age, gender, handedness and education between patients with UUMND from left versus right sided lesions. Stringent criteria for patient selection were employed to ensure that only the effects of UUMN lesions were being measured. All participants underwent physical examination, MOMFAS, and other auxiliary examinations (such as brain CT, MRI). All patients were diagnosed by neurologists and met the diagnostic criteria for UUMN approved by the Chinese Medical Association in 2015 and no rehabilitation treatment was given at this point. All patients could complete simple daily Mandarin communication. Twenty-seven patients had left hemisphere and twenty-five had right hemisphere stroke. They had no alexia, apraxia of speech, or visual or severe auditory comprehension impairments, and had pure-tone thresholds at 500, 1000, and 2000 Hz of ≤ 25 dB hearing level (HL) in at least one ear.

The control group included 38 healthy adults (HAs) in a similar age range (21 to 76 years old; mean ± SD: 45.89 ± 13.45 years). Certain participants in the HAs were family members of the dysarthria groups. The HAs had pure-tone thresholds at 500, 1000, and 2000 Hz of ≤ 25 dB HL in at least one ear with no reported hearing or speech disorders, and completed the MOMFAS, with no speech articulation issues observed.

This study was approved by the Scientific Research Ethics Committee of the Fifth Affiliated Hospital of Jinan University(approval date: March 1, 2023). The use of human subjects was reviewed and approved by the Scientific Research Ethics Committee of the Fifth Affiliated Hospital of Jinan University. The participants were all provided written informed consent. All research was performed in accordance with the relevant guidelines and regulations of the Declaration of Helsinki.

Speech materials and data collection
The present study utilized a "Mandarin dysarthria evaluation vocabulary", comprising 82 target sounds, including monophthong vowels, compound vowels, consonants, and sequence figures. This vocabulary was collaboratively developed by Jinan University in China, Ohio University, and University of Central Arkansas in the United States. All speech recordings were conducted by the same researcher. A Sony portable digital recorder (Model ZOOM H4N) was employed to record all speech samples at a 44.1-kHz sampling rate and a 16-bit quantization rate. From the vowel word list, four monosyllabic phonetic materials, such as "a1, a2, a3, a4, ba1, ba2, ba3, ba4, bi1, bi2, bi3, bi4, du1, du2, du3, du4", were extracted. All recordings were made within 48 hours of onset.

The subjective assessment method for articulatory motor function in China currently uses MOMFAS developed by Lu et al.[20]. This scale comprehensively evaluates the motor ability of the mandible, lips, and tongue from three aspects: relaxation, oral motor ability, and articulatory motor ability. The scale includes nine actions for the mandible, eight actions for the lips, and sixteen actions for the tongue. A five-level grading system is used to determine the overall severity. The advantage of this scale lies in its ability to detect even subtle changes in oral movements, helping clinicians to diagnose and analyze oral motor disorders more accurately and develop individualized treatment plans. This study applies MOMFAS to quantitatively assess the organ motor function of patients with unilateral upper motor neuron dysarthria. Mandibular motor function was evaluated using the scale for all participants. It provides a comprehensive evaluation of articulatory motor abilities of the mandible, lips, and tongue, with each sub-item graded on a 0–4 scale, representing very severe, severe, moderate, mild, and normal levels. A score of 0 represents the most severe impairment and a score of 4 represents no impairment. The total score is calculated to determine the overall severity. The lower the total score, the more severe the articulation disorder.

Two experienced speech therapists conducted MOMFAS assessments and the acoustic measurements for the participants. Both speech-language therapists completed standardized training prior to formal assessments. In the main study, the inter-rater reliability for MOMFAS total scores, assessed via ICC (2,1) (two-way random-

	Left-sided UMND group (n = 27)	Right-sided UMND group (n = 25)	t	*P*
Gender (Male/Female)	22/5	20/5	0.127	0.772
Handedness (Right/Left)	27/0	25/0	–	–
Age (Years)	71.82 ± 4.29	72.67 ± 4.26	1.137	0.275
Education (Years)	9.24 ± 2.12	9.19 ± 2.04	0.215	0.830

Table 1. General information of UUMND groups. UMND, upper motor neuron dysarthria; UUMND, unilateral upper motor neuron dysarthria.

	Project	UUMND group (n = 52)	Control group (n = 38)	t	*P*
/a/	F1	578.83 ± 23.26	629.64 ± 11.52	− 8.47	< 0.01
	F2	1534.57 ± 62.63	1462.29 ± 53.15	7.26	< 0.01
/i/	F1	419.97 ± 35.59	383.41 ± 10.61	12.27	< 0.01
	F2	1896.22 ± 46.30	1989.36 ± 38.75	− 7.65	< 0.01
/u/	F1	418.06 ± 48.10	402.34 ± 6.48	0.117	0.124
	F2	1472.36 ± 81.61	1166.57 ± 32.92	20.57	< 0.01

Table 2. Statistical results of F1 and F2 parameters of vowel/a/, /i/, /u/ between UUMN dysarthria group and normal controls. (UUMN: unilateral upper motor neuron).

	Project	Left-sided UMND group (n = 27)	Right-sided UMND group (n = 25)	*t*	*P*
/a/	F1	583.28 ± 78.28	573.52 ± 67.41	− 1.00	0.187
	F2	1540.34 ± 89.51	1528.24 ± 89.34	1.08	0.141
/i/	F1	426.14 ± 22.18	413.14 ± 25.20	2.75	< 0.01
	F2	1955.85 ± 131.00	1837.84 ± 125.76	7.85	< 0.01
/u/	F1	418.43 ± 55.70	417.65 ± 38.51	0.12	0.453
	F2	1595.61 ± 155.45	1349.33 ± 95.54	14.10	< 0.01

Table 3. Statistical results of F1 and F2 parameters of vowel/a/, /i/, /u/ between Left-sided UMND and Right-sided UMND groups. UMN, upper motor neuron; UMND, upper motor neuron dysarthria.

effects, absolute agreement), was 0.873 (95% CI 0.81–0.92), exceeding the clinical threshold. All ratings were performed under blinding procedures.

Consequently, 1440 monosyllabic samples were obtained from the UUMN dysarthria group. The recording took place in the sound insulation therapeutic room and soundproof room of the First Affiliated Hospital of Jinan University. Throughout the recording process, participants were seated upright, while the researcher held the recorder approximately 10 cm from their lips. Participants were instructed to speak naturally with a moderate volume, and each word in the vocabulary was repeated twice. For acoustic analysis, the first valid sample of each word with each tone was selected for each participant.

Data processing

These recorded materials were divided into separate syllables and saved as individual wave files using CoolEdit (Syntrillium Software, Scottsdale, AZ, Pro2.1, URL: https://www.filehorse.com/download-cool-edit-pro/). Praat (Special speech software, version 6.4.27, URL: https://www.fon.hum.uva.nl/praat/) was used to determine the frequencies of the first two formants, F1 and F2, at the midpoint location over the course of the vowel duration in each token. Referring to Yang's research[21], the formant extraction was conducted through linear predictive coding analysis, and the extracted formant tracks were displayed on the spectrogram. Manual correction was carried out for any errors found in the automatic extraction. The onset and offset of each vowel were determined by visually inspecting the waveform and spectrogram. The vowel onset was set at the zero-crossing point of the first period with a visible formant track, while the vowel offset was marked at the point where periodicity ceased and the formant track was no longer visible. To eliminate variations in formant frequency values attributed to physiological differences (e.g., vocal tract sizes associated with gender and age) in the speakers, all formant frequency values were normalized using the Lobanov method[22]. Then, the data of vowel F1 and F2 were imported into an Excel file, and the VSA, VAI, and FCR were constructed from these data[15,23–25].

Statistical analysis

Following tests for normal distribution and homogeneity of variance, it was determined that the data met the assumptions of normal distribution and homogeneity of variance. The measurement data and the scores of MOMFAS were expressed as mean ± standard deviation, and comparisons between groups were conducted using an independent samples t-test. Count data were presented as frequencies and within-group comparisons were performed using one-way ANOVA. The *P*-values for the multiple comparisons of different lesion sites in bilateral strokes have been adjusted in this study.

Results

F1, F2

Patients with UUMND exhibited significant articulatory deviations compared to controls (Table 2), marked by elevated /a/F2, /i/F1, and /u/F2 alongside reduced /a/F1 and /i/F2 ($P < 0.01$), while /u/F1 remained comparable ($P > 0.05$). Lateralization patterns further emerged in left-sided lesions (Table 3), which demonstrated higher /i/F1, /i/F2, and /u/F2 than right-sided cases ($P < 0.01$), whereas no interhemispheric differences were observed in /a/F1, /a/F2, or /u/F1 ($P > 0.05$). These findings highlight left-lateralized articulatory impairment and vowel-specific hemispheric modulation in UUMND.

	VSA	t	P
UUMND group (n = 52)	44,956.43 ± 15,870.49	11.74	< 0.01
Control group (n = 38)	96,189.75 ± 7724.04		
Left-sided UMND group (n = 27)	41,383.89 ± 11,901.76	− 3.51	< 0.01
Right-sided UMND group (n = 25)	48,528.97 ± 15,254.86		

Table 4. Statistical results of VSA parameters among the UUMND group and normal controls, and the Left-sided and Right-sided UMND groups. The unit of VSA is Hz^2.

	FCR	t	P
UUMND group (n = 52)	1.56 ± 0.12	25.669	< 0.01
Control group (n = 38)	1.30 ± 0.02		
Left-sided UMND group (n = 27)	1.59 ± 0.13	3.02	< 0.01
Right-sided UMND group (n = 25)	1.52 ± 0.11		

Table 5. Statistical results of FCR parameters among the UUMND group and normal controls, and the Left-sided and Right-sided UMND groups. FCR has no unit.

	VAI	t	P
UUMND group (n = 52)	0.64 ± 0.06	7.25	< 0.01
Control group (n = 38)	0.77 ± 0.01		
Left-sided UMND group (n = 27)	0.63 ± 0.05	− 3.44	< 0.01
Right-sided UMND group (n = 25)	0.65 ± 0.05		

Table 6. Statistical results of VAI parameters among the UUMND group and normal controls, and the left-sided and right-sided UMND groups. VAI has no unit.

	The score of MOMFAS	t	P
Left-sided UMND group (n = 27)	79.56 ± 9.192	8.90	< 0.01
Right-sided UMND group (n = 25)	100.56 ± 7.660		

Table 7. The results of MOMFAS of left-sided and right-sided UMND groups.

VSA, VAI, FCR

Tables 4, 5, and 6 show that patients with UUMND had significantly reduced VSA and VAI, but higher FCR compared to healthy controls (all $P < 0.01$). Left-sided lesions were associated with significantly greater deficits in all three acoustic measures than right-sided lesions (all $P < 0.01$).

Scores of MOMFAS

The mean value of scale score in the left-sided UMND group was significantly lower than that in the right-sided UMND group ($P < 0.01$), indicating that the overall severity of dysarthria in left-sided stroke was higher than that in right-sided stroke (Table 7).

Discussion

F1, F2

This study evaluated acoustic vowel parameters in UUMND. F1 increased during /a/ production (mandibular shift, tongue lowering) but decreased during /i/ and /u/ articulation (tongue elevation), reflecting pharyngeal cavity modulation. F2 elevation (tongue advancement in /i/) and reduction (retraction in /u/, /a/) indicated oral cavity dimensional changes[26,27]. Notably, vowels with higher F1 frequencies exhibited longer durations across languages, likely due to jaw movement physiology.

Additionally, the rounding of the lips has an impact on the F1 and F2 frequencies. When the lips are sufficiently rounded, both F1 and F2 frequencies decrease, but they rise when the lips are insufficiently rounded and are retracted[27]. UUMND patients exhibited distinct vowel articulation deficits versus controls: elevated /a/F2, /i/F1, /u/F2 and reduced /a/F1, /i/F2, indicating impaired mandibular descent (/a/), restricted tongue elevation/advancement (/i/), and insufficient lip rounding with retraction limitation (/u/). Vertical tongue movement (/u/F1) remained unaffected, suggesting selective articulatory pathophysiology.

The above observations manifest that the high-low and front-back movements of the tongue in patients with UUMND would be affected to varying degrees compared with the control group, especially when the tongue is positioned high to produce high vowels. The results are inconsistent with the study conducted by Mou et al. on children with cerebral palsy, who mainly found that the F1 of /a/ in the children group was greater than that of the normal adult group, while the F2 of /a/ and /i/ was less than that of the normal group[11]. The disparity in these findings may stem from differences in the dysarthria subtypes studied, with Mou et al. not clearly categorizing the subtypes of dysarthria during case selection. Different dysarthria subtypes are characterized by distinct manifestations of speech disorders[11].

Statistically significant differences ($P<0.01$) were observed in the mean values of /i/F1, /i/F2, and /u/F2 between Left-sided UMND and Right-sided UMND groups (Table 3). Specifically, /i/F1, /i/F2, and /u/F2 were significantly higher in left-sided UMND group than in right-sided UMND group. Given prior evidence linking F1 and F2 to speech intelligibility, we hypothesize that left-sided UMND patients, exhibiting reduced articulatory organ mobility, may demonstrate lower speech intelligibility compared to right-sided UMND patients when producing vowels /a/, /i/, and /u/[18,28]. However, there was no statistically significant difference ($P>0.05$) in the mean values of /a/F1 and /u/F1 between left-sided UMND and right-sided UMND groups, so we may speculate that front-back movement of the tongue is more restricted in individuals with left-sided UMND in relation to high-low movement (Table 3). The reason for the result may be that the extrinsic lingual muscles are not completely involved after stroke so the high-low movement of the tongue is partially preserved. The above conclusions suggest that during the rehabilitation of dysarthria patients, clinical speech therapists should focus on strengthening the internal tongue muscles to increase the range of vocal organ motion, thereby improving the effectiveness of rehabilitation therapy.

VSA, VAI, FCR

VSA is a commonly utilized acoustic measure for assessing vowel production in individuals with dysarthria. Our study found a substantial decrease in VSA among patients diagnosed with UUMND compared to normal controls (Table 4). This finding aligns with the conclusions drawn by Ge et al. and Mou et al. who also observed reduced VSA in patients with spastic dysarthria[19,29]. In contrast, Lansford & Liss et al. investigated the acoustic indices of vowels in 45 patients with dysarthria caused by neurological disorders as well as 12 healthy adults[16]. They found that while VSA effectively differentiated dysarthric patients from normal individuals, it was not a reliable indicator for distinguishing between different subtypes of dysarthria. Additionally, they noticed a greater sensitivity of VSA in moderate and severe cases of dysarthria, with lower sensitivity in mild cases. Despite the predominance of mild-to-moderate UUMND cases in this cohort, the observed sensitivity of VSA measurements may be explained by two interrelated factors. First, the linguistic characteristics of Mandarin—including its tonal system, segmental structure, and smaller vowel inventory compared to English—likely enhance the detectability of subtle articulatory deviations, even in individuals with mild impairment. Second, while continuous vocalization tasks (e.g., sustained phonation of /a/) might unintentionally prolong vowel duration and reduce articulatory dynamics, this limitation was mitigated by prioritizing ecologically valid speech sampling. Participants produced vowels within spontaneous speech at their habitual conversational pace, preserving natural articulatory patterns and improving the sensitivity and ecological validity of VSA assessment.

Prior studies have established significant correlations between VSA, vowel concentration patterns, and dysarthria severity in motor speech disorders[9]. FCR and VAI exhibit an inverse correlation, while all three indices (FCR, VAI, VSA) collectively reflect impaired tongue-oral coordination capacity[30]. Unlike VSA, VAI and FCR improve detection of subclinical dysarthria by minimizing population variance through ratio standardization[31], yet FCR's 50% false-negative rate in mild cases reveals critical sensitivity limitations[16]. FCR tends to increase with vowel concentration, while changes in VAI demonstrate the opposite pattern, resulting in reduced speech intelligibility when vowel concentration increases[26]. It has negative implications for patients' daily communication. Within the context of this study, VAI and FCR were applied for the first time to assess vowel changes in Mandarin-speaking post-stroke patients with UUMND. These findings align with prior observations of similar articulation deficits in Parkinsonian and multiple sclerosis dysarthria despite differing etiologies[31,32]. UUMND patients exhibited significantly elevated FCR and reduced VAI (Tables 5–6), demonstrating pathological vowel resonance clustering that reflects constrained articulatory mobility and systematic vowel space compression.

Significant lateralization effects emerged in UMND pathophysiology, with left-sided cases demonstrating elevated FCR (Table 5) and reduced VSA/VAI (Tables 4,6) compared to right-sided lesions (all $P<0.01$). The balanced cohort (left-sided cases: $n=27$; right-sided cases: $n=25$) demonstrated significantly greater dysarthria severity in left-hemisphere lesions compared to right-sided counterparts ($P<0.01$), corroborating established left-lateralized pathophysiology[5]. This lateralization pattern was confirmed by MOMFAS assessments, with significantly lower scores in left-sided UMND versus right-sided groups (Table 7). However, functional hemispheric differentiation remains incomplete, as right hemisphere contributions to articulatory control persist, albeit secondary to dominant left-hemisphere networks. These findings align with prior evidence demonstrating left-hemisphere lesions universally induce more severe dysarthria regardless of lesion topography[4–6]. This study provides supporting evidence for prior research on left-sided lateralization, though further studies are needed to confirm this phenomenon. As a prospective investigation, it characterizes the severity of UUMND by lesion side, offering insights into improving articulatory motor function in post-stroke patients. By analyzing acoustic speech characteristics, our findings enhance the understanding of UUMND. However, the sample size was limited; future studies should expand recruitment and control for gender distribution to strengthen generalizability.

These findings advance the quantification of acoustic properties in post-stroke UUMND among Mandarin speakers, enhancing the laboratory-based understanding of this dysarthria. By characterizing phonetic impairments—particularly vowel imprecision and aberrant articulatory patterns—this study underscores the clinical relevance of stroke-related dysarthria. The results may inform objective dysarthria assessment and guide targeted rehabilitation strategies. Future research should expand to compound vowels, consonants, and tonal features to further elucidate speech motor deficits in UUMN.

Conclusion

In this study, we conducted acoustic analysis on healthy adults and native Mandarin-speaking UUMN patients, as well as UUMN patients with different sides of stroke, and the specific acoustic parameters F1, F2 and VSA, FCR, VAI show some differences among the above groups. Meanwhile, our study provides new supportive evidence for left-sided lateralization of UUMND based on these parameters and the results of MOMFAS. The study would provide valuable guidance for rehabilitation treatment in Mandarin-speaking individuals with UUMND.

Data availability

The datasets generated during the current study are available from the corresponding author on reasonable request.

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Author contributions
Yiqi Cao and Yazhuo Cheng were the co-first authors of the article, and contributed to the work equally. Z. M. made contribution to conception and design, and reviewed and revised the manuscript. S. L. conducted literature research. Yiqi Cao and Yazhuo Cheng recruited patients, collected clinical data and drafted the initial manuscript. Yiqi Cao, Yazhuo Cheng and S. L. reviewed and revised the manuscript, and conducted the data analyses. S. L. and Z. M. critically reviewed the manuscript for important intellectual content. All authors read and approved the final manuscript. Correspondence to Zhiwei Mou.

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Declarations

Competing interests
The authors declare no competing interests.

Ethical approval
This study was approved by the Scientific Research Ethics Committee of the Fifth Affiliated Hospital of Jinan University(approval date: March 1, 2023). The use of human subjects was reviewed and approved by the Scientific Research Ethics Committee of the Fifth Affiliated Hospital of Jinan University. The participants were all provided written informed consent. All research was performed in accordance with the relevant guidelines and regulations of the Declaration of Helsinki.

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