Production of the Arabic Phoneme /r/ in Post-Ischemic Stroke Patients: A Phonetic Analysis Based on Harakat Variation

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ABSTRACT

Neuromotor disorders due to ischemic stroke often affect articulatory control, especially tongue movements that play a crucial role in the production of speech sounds. In Arabic phonetics, the phoneme [ṛ] is a letter *of al-lisān* that relies heavily on the precision of tongue tip movement against the alveolar ridge. However, studies specifically examining the articulatory realization of this phoneme in post-ischemic stroke patients during controlled recitation of the Qur'an are still relatively limited. This study examines the effect of variations in vowels, namely *fathah, kasrah, and dhammah*, on the production of the phoneme [ṛ] in a post-ischemic stroke patient. The study used a qualitative case study design based on Peter Ladefoged's *Articulatory Phonetics theory*. Data were obtained through recordings of participants' recitations, then analyzed in Praat to identify acoustic parameters, including duration, fundamental frequency (F0), intensity, and formant patterns. The results showed that the production of the phoneme [ṛ] experienced changes in acoustic characteristics with each variation of the vowel. The *dhammah* /ru/ variation shows the most prominent deviation through duration lengthening and acoustic instability, while the *kasrah* /ri/ shows duration shortening accompanied by a decrease in sound energy. These findings indicate impaired articulatory coordination, particularly in tongue-tip movement and oral resonance stability. This research contributes to the development of clinical phonetic studies and to the objective evaluation of speech disorders through acoustic analysis.

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1. INTRODUCTION

Language as a system of speech sounds is produced through the complex coordination of articulatory organs, especially the tongue, lips, jaw, and palate (Døli et al.,

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2021; Khwaileh et al., 2025). In the study of articulatory phonetics, each phoneme has production characteristics that depend on the position and movement of the speech organs involved in the sound formation process. This process involves not only physiological aspects, but also neuromotor coordination that allows for synchronization between neural commands and the movement of the articulatory muscles (Kaur et al., 2022; Schreiner et al., 2022) In Arabic, one of the letter classifications based on *makhraj* (place of articulation) shows the existence of a group of letters called *al-lisān*, namely letters that rely on the tongue as the main articulator (Ali et al., 2023; Liu et al., 2022). The production of these letters requires precise positioning, flexibility, and stability of tongue movement, as slight changes in position or pressure can produce significant differences in sound quality (Almarwani & Alhamyani, 2025; Farisi et al., 2025). In the practice of reciting the Qur'an, articulation accuracy is a crucial element, as inaccurate sound realization can affect clarity, pronunciation accuracy, and overall phonetic quality (Picano et al., 2021; Simic et al., 2021).

Disorders of the neuromotor system can affect a person's ability to control the articulatory organs, including the tongue as a major component of speech sound production (Algaraady et al., 2025; DeLeon, 2021). One medical condition that often impacts motor function is ischemic stroke, which is a disruption of blood circulation in the brain that causes damage to certain nerve tissue (De Cock et al., 2021; Iskarous & Vietti, 2025). This damage can disrupt the coordination of speech muscles, leading to difficulties with articulation, clarity of pronunciation, and stability of sound production (Malicka-Podkalicka, 2024; Padmini et al., 2021). In some cases, individuals after a stroke experience dysarthria, characterized by weak control of tongue movements, delayed motor responses, and irregular sound vibration patterns (Alaqeel et al., 2022; Keung et al., 2024). One letter that is highly dependent on the precision of tongue movement is the letter ر, which is phonetically represented as [ɾ], because this sound is produced by the touch or rapid vibration of the tip of the tongue on the alveolar region. Disturbances in tongue coordination have the potential to significantly affect the quality of realization of this phoneme (Llico et al., 2023; Mutlak & Kareem, 2025).

Several studies have examined the impact of post-stroke neurological impairment on the acoustic and articulatory characteristics of speech. Adem (2025) showed that Arabic-speaking individuals with Broca's aphasia exhibited increased formant variability (F2 and F3), prolonged Voice Onset Time (VOT), and decreased sound intensity, indicating impaired coarticulation dynamics. Furthermore, Cao et al. (2025) found that the parameters F1, F2, Vowel Space Area (VSA), Vowel Articulation Index (VAI), and Formant Centralization Ratio (FCR) significantly reflected the severity of dysarthria due to upper motor neuron lesions, particularly in the left hemisphere. Meanwhile, Siddique et al. (2025) also reported consistent VOT lengthening in individuals with dysarthria compared to healthy controls. In the Arabic context, Nurfitri et al. (2025) identified variations in the articulation of the phoneme /l/ in post-stroke patients across vocalic contexts using Praat-based analysis. Meanwhile, Han et al. (2024) explained that changes in speech performance after stroke are related to the plasticity of the perilesional network and the reorganization of language pathways in the brain.

In addition to segmental analysis, other studies have highlighted aspects of clinical assessment and therapeutic intervention in post-stroke dysarthria. Chiaramonte and Vecchio (2021) demonstrated through a systematic review that acoustic parameters, Alternating Motion Rate (AMR), Sequential Motion Rate (SMR), and maximum phonation time, are sensitive in measuring severity and response to speech rehabilitation. Furthermore, Ge et al. (2021) found that vowel production in post-stroke spastic dysarthria

experiences significant centralization, with metrics such as F2 range, VSA, VAI, and FCR effectively predicting articulation performance. Furthermore, Fadel et al. (2025) confirmed that acoustic measures, such as the Acoustic Voice Quality Index (AVQI), jitter, and formant analysis, can objectively identify phonation and articulation dysfunction. In the Arabic context, Summaka et al. (2024) validated the Arabic version of the Radboud Dysarthria Assessment and demonstrated a strong correlation between the maximum performance task and Praat analysis. Meanwhile, Srinivasan and Narayanan (2025) demonstrated that "Be Clear" therapy significantly improved intelligibility, FCR, F2 slope, and articulation rate in individuals with post-stroke dysarthria.

Although numerous studies have investigated the acoustic characteristics of dysarthria and post-stroke speech disorders, most have primarily focused on general vowel parameters, plosive sounds, or clinical assessments of speech impairment severity. Furthermore, limited attention has been given to the articulation of specific phonemes within the controlled context of Qur'anic recitation. The research gap addressed in this study is the absence of investigations specifically examining the articulation of the phoneme ر [ɾ], classified as a *ḥarf al-lisān* (tongue consonant), in patients with ischemic post-stroke, across different vowel diacritics (*ḥarakāt*) within a consistent recitation corpus, namely *Surah Al-Qāri'ah*. Accordingly, the research problem concerns the lack of understanding of how the vowel diacritics *fatḥah*, *kasrah*, and *ḍammah* influence the articulatory and acoustic characteristics of the phoneme ر [ɾ] in Qur'anic recitation produced by patients with ischemic post-stroke. This issue is particularly significant because the phoneme ر is an alveolar tap whose production relies heavily on precise tongue-tip contact with the alveolar ridge and stable articulatory coordination. Within the framework of Articulatory Phonetics proposed by Ladefoged (2015), any modification in articulatory configuration results in corresponding phonetic and acoustic consequences. Consequently, neuromotor impairments caused by ischemic stroke are likely to systematically affect the realization of this phoneme. The novelty of this study lies in its application of the Articulatory Phonetics framework to analyze the production of the phoneme ر [ɾ] in *Surah al-Qāri'ah* by patients with ischemic post-stroke through an empirical acoustic approach. This study is expected to contribute to integrating Arabic phonetics into neurological speech disorder research, while providing a foundation for using acoustic parameters as objective measures for speech evaluation and for developing more targeted articulatory rehabilitation strategies. Therefore, this study aims to examine how the vowel diacritics *fatḥah*, *kasrah*, and *ḍammah* influence the articulatory realization of the phoneme ر [ɾ] in patients with ischemic post-stroke.

2. METHOD

2.1 Research Design

This study employed a qualitative case study design. A qualitative approach was selected because it aims to achieve an in-depth understanding of a phenomenon within its natural setting from the participants' perspectives (Creswell, 2014). Meanwhile, the case study design was adopted to comprehensively explore the articulatory characteristics of the phoneme ر [ɾ] in a single clinical case within a real-life context. According to Yin (2014), a case study is appropriate when the research focuses on a contemporary phenomenon that requires an in-depth investigation, while considering the context in which it occurs. Therefore, the use of a single participant was considered appropriate for the characteristics of case study research, as the objective was not to achieve statistical generalization but

rather to obtain a comprehensive understanding of the articulatory characteristics of the phoneme ر [r] in a patient with ischemic post-stroke.

2.2 Research Participant

The participant was selected using purposive sampling based on characteristics relevant to the research objectives. The inclusion criteria were as follows: (1) a history of ischemic stroke, (2) the ability to recite the Qur'an with good proficiency, and (3) regular engagement in Qur'anic recitation as part of daily activities. To ensure confidentiality, the participant was assigned the code PSP (*Post-Stroke Patient*). The participant's clinical characteristics are presented in Table 1.

Table 1
Clinical Characteristics of the Research Participant

Aspect	Description
Age	52 years
Type of Stroke	Mild ischemic stroke
Affected Hemisphere	Left hemisphere
Time Since Stroke Onset	Approximately 4 years
Initial Condition	Swelling in the oral region accompanied by articulatory impairment
Comorbid Diagnosis	Cerebral palsy
Speech Disorder	Speech was difficult to understand during the first 1–2 years after stroke onset.
Rehabilitation History	Received speech therapy on three occasions
Condition at the Time of the Study	Speech was generally intelligible; however, residual tongue stiffness remained, affecting the accurate articulation of certain phonemes.

2.3 Reference Data Source

In addition to primary data from the PSP participant, this study used recordings of Sheik Mishary Rashid Alafasy (SMRA) as the normative reference for Arabic pronunciation. SMRA was selected because he is internationally recognized as a distinguished Qur'an reciter whose pronunciation consistently adheres to the rules of *tajwīd* and whose recordings are of high acoustic quality, making them suitable as a phonetic reference. In this study, the SMRA recordings were not treated as a comparison subject but rather as a model of normative pronunciation for interpreting the articulatory characteristics of the phonemes produced by the PSP participant.

2.4 Recording Procedure and Data Collection

Data collection was conducted in Garut Regency, Indonesia, in a quiet enclosed room to minimize environmental noise. The participant's speech was recorded using a Mix Sounds Series A37 microphone and stored in digital (.wav) format to preserve signal quality throughout the acoustic analysis. The participant was instructed to recite *Surah al-Qāri'ah* in its entirety at a natural speaking rate without any intervention from the researcher. Data were collected through structured observation of the Qur'anic recitation process, with audio recordings serving as the primary source.

2.5 Acoustic Data Analysis

All speech recordings were analyzed using the Praat software. The initial stage involved identifying every occurrence of the phoneme ر [*r*] in *Surah Al-Qāri'ah*. Each token was subsequently classified according to its vowel context: ***fatḥah***, ***kasrah***, or ***ḍammah***. Based on this identification, the analyzed tokens consisted of ***/***ra***/*** in verse 4, ***/***ri***/*** in verse 3, and ***/***ru***/*** in verse 11. Each token was then manually segmented at its onset and offset using the waveform and spectrogram displays in Praat to ensure accurate segmentation boundaries.

The acoustic parameters analyzed included duration, fundamental frequency (F0), intensity, and formant stability patterns as indicators of the articulatory characteristics of the phoneme ر [*r*]. The results obtained from the PSP participant were interpreted using the SMRA recordings as the normative pronunciation reference, enabling qualitative descriptions of differences in acoustic characteristics in accordance with the exploratory purpose of the study.

2.6 Trustworthiness of the Data

The trustworthiness of the findings was ensured through repeated measurements of each analyzed phoneme token to verify the consistency of segmentation and acoustic parameter measurements performed in Praat. Furthermore, the interpretation of the phonetic characteristics was guided by Ladefoged's (2015) Articulatory Phonetics framework and supported by comparisons with the normative pronunciation patterns produced by SMRA as the phonetic reference. The data were subsequently analyzed using the interactive analysis model proposed by Miles et al. (2020), which consists of data condensation, data display, and conclusion drawing.

3. RESULTS AND DISCUSSION

The findings of this study are presented based on the acoustic analysis of the phoneme ر [*r*] produced with three vowel diacritics (*ḥarakāt*), namely *fatḥah*, *kasrah*, and *ḍammah*, during the recitation of *Surah Al-Qāri'ah* by a patient with ischemic post-stroke (PSP). The analysis was conducted using Praat software by examining four acoustic parameters: duration, fundamental frequency (F0), intensity, and formant stability patterns. As the normative pronunciation reference, recordings of Sheik Mishary Rashid Alafasy (SMRA) were employed. Before presenting the findings for each vowel diacritic, Table 2 provides the list of target words analyzed in this study, together with their phonetic transcriptions and vowel classifications.

Table 2
Research Glossary

Letter	Analysis of Words	Phonetic Transcription	*Harakat* Category	Vocal Symbol
Surah Al-Qari'ah /4	يَوْمَ يَكُونُ النَّاسُ كَالْفَرَاشِ الْمَبْثُوثِ	/kal.fa.ra:.ʃi/	Fathah	/a/
Surah Al-Qari'ah /3	وَمَا أَدْرَاكَ مَا الْقَارِعَةُ	/qa:.ri.ʕa.tu/	*Kasrah*	/i/
Surah Al-Qari'ah /11	نَارٌ حَامِيَةٌ	/na:.run/	Dhammah	/u/

Table 2 shows a list of speech data used in the study to analyze the articulation of the phoneme ر [ɾ] based on the variation of vowels in Surah Al-Qāri'ah. The data selection focused on three main vowel categories, namely *fathah* /a/, *kasrah* /i/, and *dhammah* /u/. Each data is presented in the form of verse fragments, phonetic transcriptions, vowel categories, and vowels accompanying the target phoneme. The selection of these three forms aims to see how vowel variations affect the articulatory realization of the phoneme ر [ɾ], especially in post-ischemic stroke subjects, so that differences in sound characteristics in each phonetic environment can be observed.

3.1 Visualization of the Phoneme ر [ɾ] in the Fathah Vowel Variation /a/

The following shows a spectrogram that describes the realization of the phoneme ر [ɾ] with the vowel /a/ in the word /al.fa.raː.ʃi/ in the SMRA reading as a reference for fluent pronunciation and PSP as the research subject.

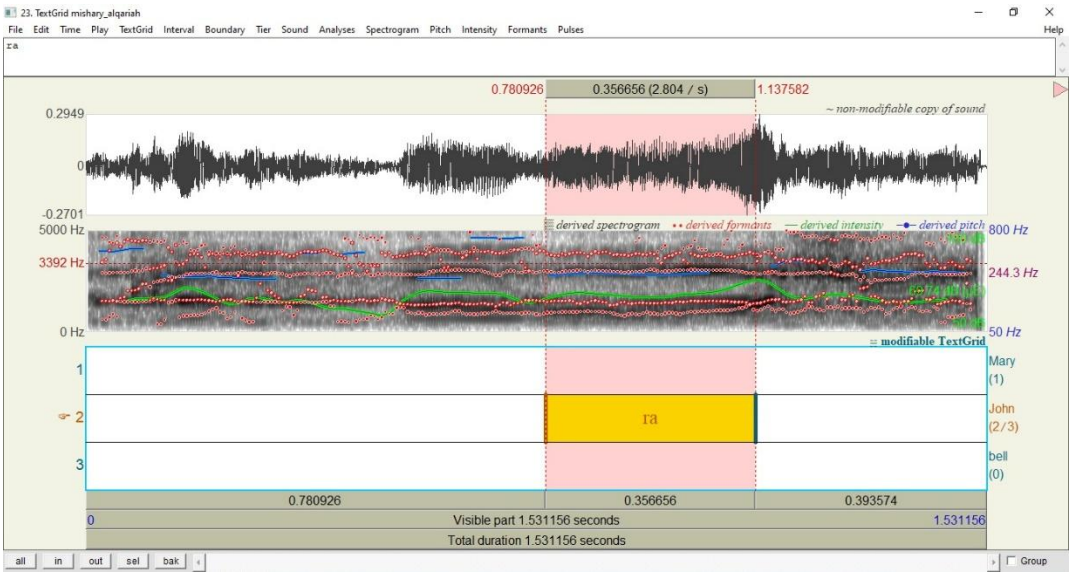

Fig. 1. Spectrogram Visualization of the pronunciation of the phoneme ر [ɾ] in the word /al.fa.raː.ʃi/ by SMRA

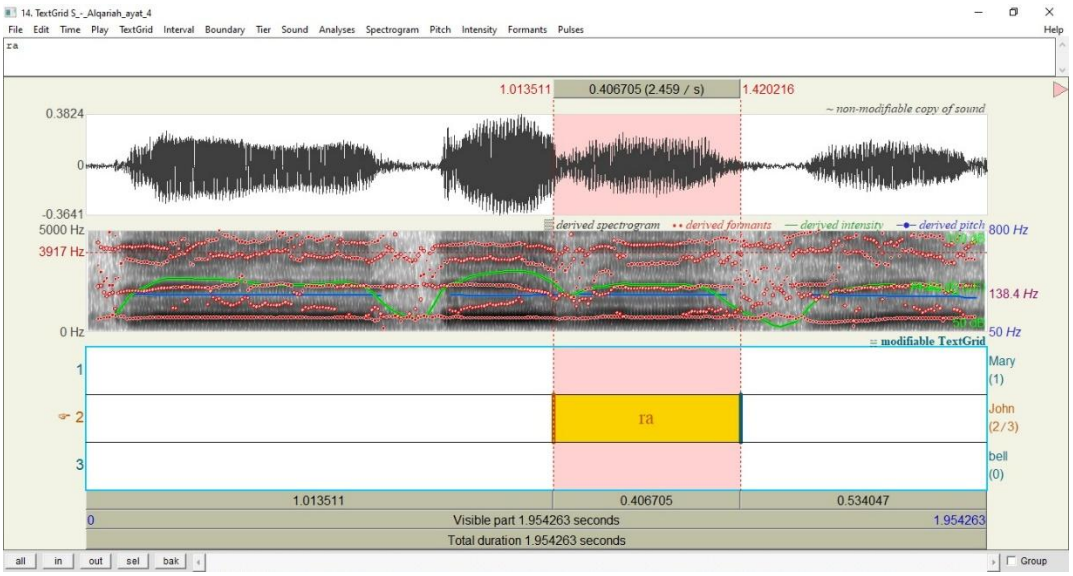

Fig. 2. Spectrogram Visualization of the pronunciation of the phoneme ر [ɾ] in the word /al.fa.raː.ʃi/ by PSP

Spectrogram 1 illustrates the acoustic visualization of the pronunciation of the phoneme ر [*r*] in the /ra/ token produced by SMRA. Overall, the waveform and spectrogram exhibit a well-organized energy distribution and clear acoustic transitions, serving as the normative reference for pronunciation in this study. Meanwhile, Spectrogram 2 presents the acoustic visualization of the pronunciation of the phoneme ر [*r*] in the /ra/ token produced by the PSP participant. Visually, several differences can be observed compared with the reference spectrogram, particularly in terms of energy distribution and the stability of the acoustic patterns. These differences are discussed in detail in the following section.

The production of the phoneme ر [*r*] in the syllable “ra” shows a difference in acoustic characteristics between the spectrograms of SMRA (1) as a reference for fluent pronunciation and PSP (2) as the research subject. PSP produces the syllable /ra/ with a duration of 0.406 seconds, while in SMRA the duration is 0.356 seconds, which indicates a lengthening of the duration of about 14.1%. In addition, PSP shows a lower fundamental frequency (F0) of 138.4 Hz compared to SMRA at 244.3 Hz. This difference indicates that PSP’s sound production tends to be less stable and has lower phonation energy. The sound intensity in PSP is also recorded at 64.05 dB, lower than SMRA, which reaches 69.74 dB. Spectrographically, the formant pattern in PSP appears more spread out and less consistent, while SMRA shows a more regular energy distribution with a clear /a/ vowel transition. These findings suggest that the realization of the phoneme ر [*r*] in PSP experiences articulatory deviation, especially in the coordination of the tip of the tongue and the stability of the oral cavity resonance when producing sounds with the vowel *fathah*.

From the perspective of *Articulatory Phonetics*, Ladefoged (2015), the phoneme ر [*r*] is classified as an alveolar tap sound produced by a quick touch of the tongue tip to the alveolar ridge. The production of this sound requires precise motor coordination, rapid tongue movement, and stable airflow control (De Cock et al., 2021; Mahyoob, 2021). The lengthening of duration and decrease in fundamental frequency in PSP indicate that the articulatory movement is less efficient than in fluent pronunciation patterns (Hussein et al., 2022; Siddique et al., 2025). This condition can be interpreted as a delay in tongue contact or a decrease in the tongue tip’s agility in producing the brief vibration that is the main characteristic of the tap sound. In the context of the vowel fathah /a/, a more open oral cavity should support clear resonance, but in PSP, the resonance pattern appears less stable so that the sound quality of ر [*r*] experiences acoustic changes (DeLeon, 2021; Fadel et al., 2025).

These findings align with Adem’s (2025) research, which showed that speakers with neurological disorders experience increased formant variability, lengthened segmental duration, and acoustic pattern instability due to impaired speech coordination. These similarities are evident in the PSP data, which show a wider formant distribution and longer phoneme duration than in the fluent reference pattern (Adem, 2025). Furthermore, these results also reinforce the findings of Nurfitri et al. (2025) that post-stroke neuromotor impairment can affect the precision of Arabic phoneme articulation in certain vowel contexts. Thus, the phoneme ر [*r*] in the fathah variation can be viewed as a sensitive indicator for identifying changes in articulatory control in post-ischemic stroke patients (Nurfitri et al., 2025).

3.2 Visualization of the Phoneme ر [ɾ] in the Variation of the *Kasrah* Vowel /i/

The following shows a spectrogram that describes the realization of the phoneme ر [ɾ] with the vowel /i/ in the word /ri/ in the SMRA reading as a reference for fluent pronunciation and PSP as the research subject.

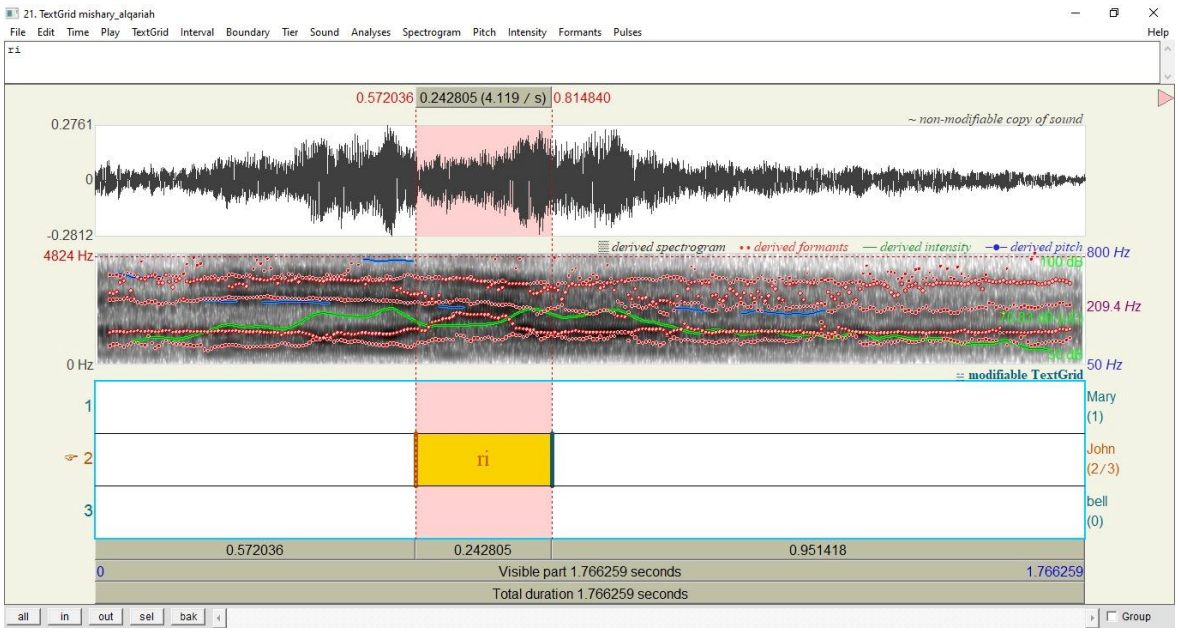

Fig. 3. Spectrogram Visualization of the pronunciation of the phoneme ر [ɾ] in the word /qaː.ri.ʕa.tu/ by SMRA

Spectrogram 3 illustrates the acoustic visualization of the phoneme ر [ɾ] in the /ri/ token produced by SMRA. The spectrogram demonstrates a clear transition toward the front vowel with a relatively stable energy distribution, providing a normative model of pronunciation.

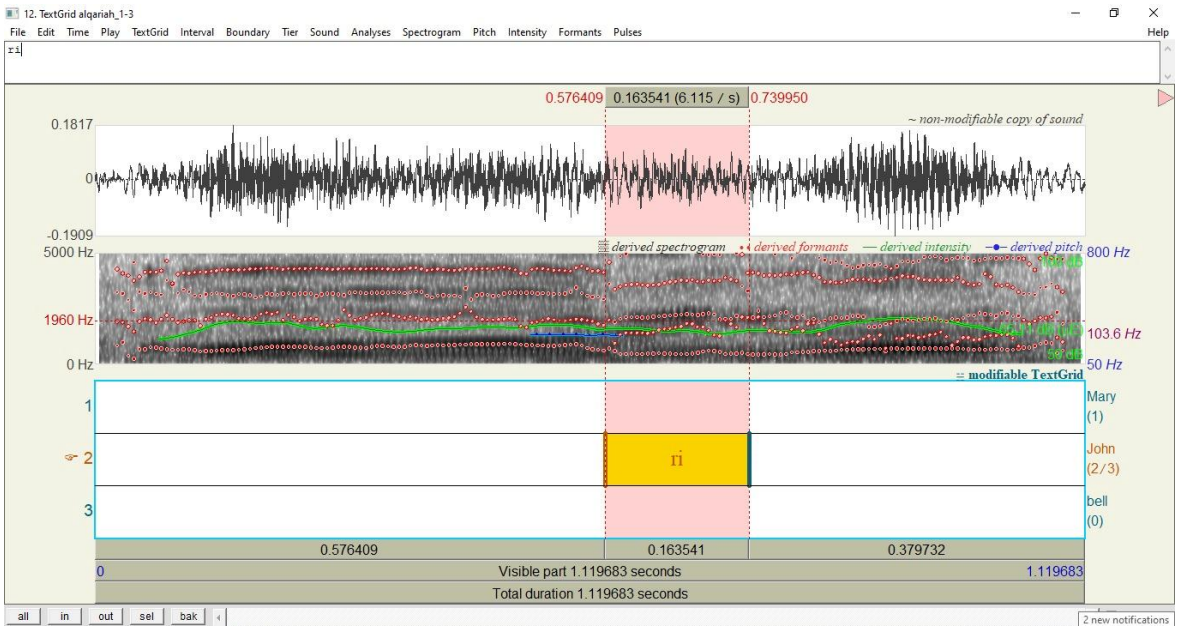

Fig. 4. Spectrogram Visualization of the pronunciation of the phoneme ر [ɾ] in the word /qaː.ri.ʕa.tu/ by PSP

Spectrogram 4 presents the acoustic visualization of the pronunciation of the phoneme ر [ɾ] in the /ri/ token produced by the PSP participant. In general, variations in the energy distribution and spectrographic stability are observed and further analyzed in the Discussion section based on the acoustic parameters.

Analysis of the sound ر [ɾ] in the syllable “ri” shows a difference in acoustic patterns between the SMRA (3) data as a reference for fluent pronunciation and the PSP (4) as the research subject. In the PSP, the production duration of /ri/ was recorded at 0.163 seconds, while in the SMRA it reached 0.242 seconds, resulting in a shortening of the duration of around 32.6%. The fundamental frequency (F0) in the PSP was also around 103.6 Hz, much lower than the SMRA of 209.4 Hz. This indicates that phonation in the PSP tends to be less stable and less powerful. The sound intensity of the PSP was recorded at 66.11 dB, while the SMRA reached 70.83 dB. Visually, the formant pattern in the PSP appeared more spread out and irregular. At the same time, the SMRA showed a more consistent energy distribution with a clear /i/ vowel transition and a tendency for a high F2 as a characteristic of front vowels. This condition indicates that the production of the phoneme ر [ɾ] in PSP experiences articulatory coordination disorders, especially in the movement of the tongue towards a high-front position when producing the *kasrah* vowel.

Reviewed through the framework *of Articulatory Phonetics*, Ladefoged (2015), the sound ر [ɾ] is an alveolar tap that requires a quick touch of the tongue tip on the alveolar ridge, while the vowel /i/ is produced with the tongue in a high and forward position. Rapid transitions between tap movements and high-front vowel configurations require good motor precision (Algaraady et al., 2025; Chiaramonte & Vecchio, 2021). Shortened duration in the PSP may indicate brief or incomplete tongue contact. In contrast, the low fundamental frequency and less stable formant pattern indicate a reduced ability to maintain a consistent articulatory position. As a result, the phonetic clarity of the sound ر [ɾ] in the context of *kasrah* may decrease (Al-Mazrouei et al., 2024; DeLeon, 2021).

This phenomenon is related to the research of Cao et al. (2025), which explains that post-stroke neurological disorders can cause changes in vocal space, sound centralization, and instability of F1 and F2 parameters. This is reflected in the PSP data, which shows a less distinct /i/ vowel transition and a more random formant distribution compared to the fluent reference pattern (Cao et al., 2025; Carl & Icht, 2021). In addition, these results also support the findings of Nurfitri et al. (2025) that post-stroke neuromotor disorders can affect the precision of Arabic phoneme articulation in certain vocalic environments. Thus, the *kasrah* variation /i/ can be seen as a sensitive phonetic context for detecting tongue coordination disorders in the production of the phoneme ر [ɾ] (Nurfitri et al., 2025).

3.3 Visualization of the Phoneme ر [ɾ] in the *Dhammah* Vowel Variation /u/

The following shows a spectrogram that describes the realization of the phoneme ر [ɾ] with the vowel /u/ in the word /ru/ in the SMRA reading as a reference for fluent pronunciation and PSP as the research subject.

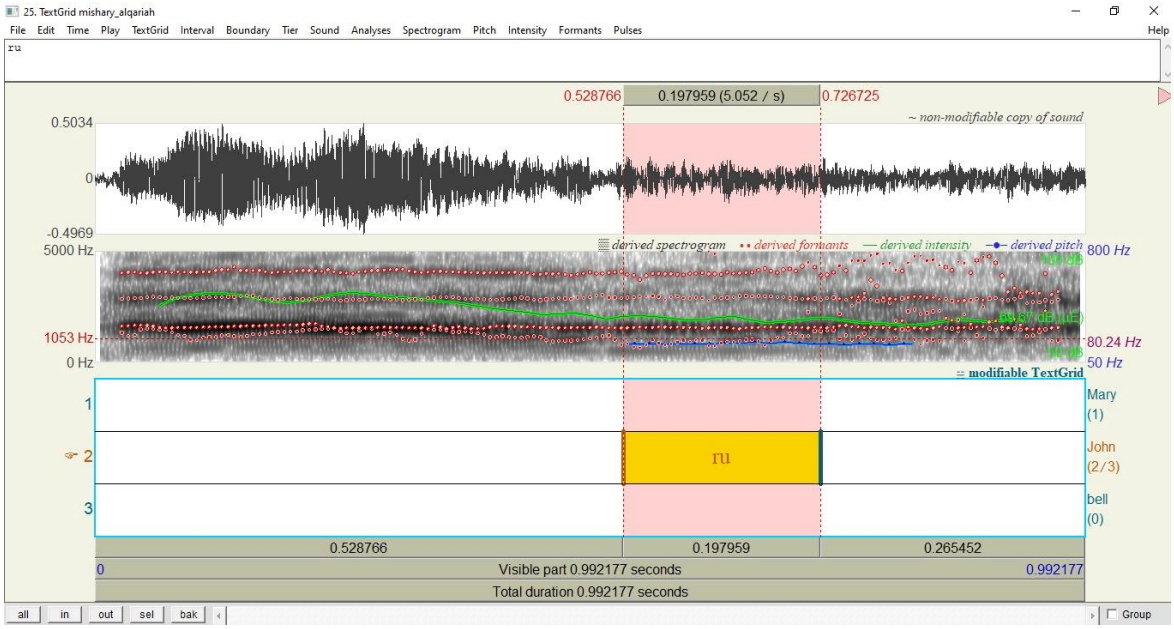

Fig. 5. Spectrogram Visualization of the pronunciation of the phoneme ر [ɾ] in the word /na:.run/ by SMRA

Spectrogram 5 illustrates the acoustic visualization of the phoneme ر [ɾ] in the /ru/ token produced by SMRA. The spectrogram exhibits a stable energy distribution with a clear transition toward the back vowel.

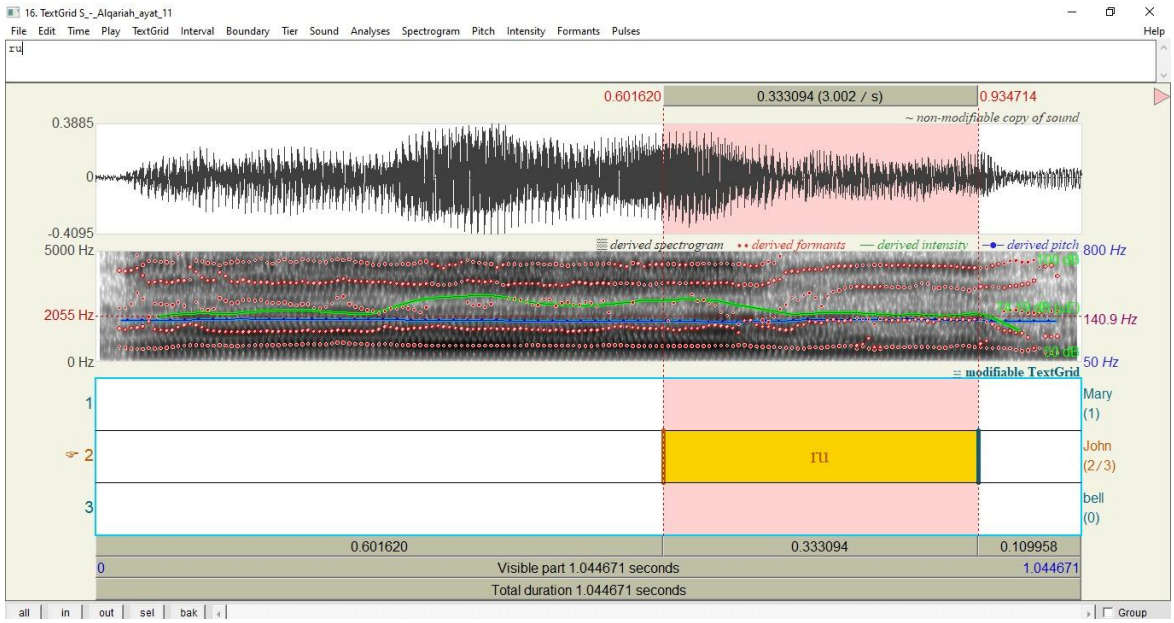

Fig. 6. Spectrogram Visualization of the pronunciation of the phoneme ر [ɾ] in the word /na:.run/ by PSP.

Spectrogram 6 presents the acoustic visualization of the pronunciation of the phoneme ر [ɾ] in the /ru/ token produced by the PSP participant. Compared with the reference spectrogram, noticeable differences are observed in the energy distribution and overall acoustic characteristics. These findings are subsequently analyzed and discussed in the following section.

Observations of the sound ر [*r*] in the syllable *"ru"* show differences in acoustic characteristics between the SMRA (5) data as a reference for fluent pronunciation and the PSP (6) as the research subject. In the PSP, the production duration of /ru/ reaches 0.333 seconds, while in the SMRA it is only 0.198 seconds, resulting in a lengthening of the duration of about 68.2%. The fundamental frequency (F0) in the PSP is recorded at 140.9 Hz, higher than the SMRA, which is around 80.24 Hz. The sound intensity of the PSP also reaches 74.69 dB, while the SMRA is 69.67 dB. Visually, the formant pattern in the PSP appears more spread out and less regular. At the same time, the SMRA shows a more consistent energy distribution with a clear /u/ vowel transition and a tendency for low formants as a characteristic of high back vowels. The greater energy fluctuation in the PSP indicates that sound production is unstable, even though the sound intensity appears higher. This condition shows that the realization of the phoneme ر [*r*] in PSP experiences articulatory deviation, especially in the coordination of the tongue moving backward and the rounding of the lips when producing the vowel *dhammah*.

If we refer to the theory *of Articulatory Phonetics*, Ladefoged (2015), the sound ر[*r*] is produced by a brief touch of the tip of the tongue on the alveolar ridge, while the vowel /u/ requires a high tongue position at the back, accompanied by rounding of the lips. The transition from a tap movement to a high back vowel configuration requires good articulatory synchronization between the tongue and lips (Srinivasan & Narayanan, 2025; Summaka et al., 2024). The lengthening in the PSP may indicate a slowing of the articulatory movement, while the high intensity and fundamental frequency may reflect a greater phonatory effort to maintain sound clarity. However, the unstable distribution of formants indicates that the increase in energy is not fully accompanied by good resonance control. As a result, the phonetic quality of the sound ر [*r*] in the context of *dhammah* has the potential to be distorted (Chiaramonte & Vecchio, 2021; Yeo et al., 2021).

This pattern is related to research by Adem (2025), who reported that neurological disorders can cause increased acoustic variability, formant instability, and changes in segmental duration due to impaired speech coordination. Similar results are seen in PSP data, which show longer duration and a more diffuse formant distribution compared to the fluent reference pattern (Kaur et al., 2022; Schreiner et al., 2022). Furthermore, these results align with those of Nurfitri et al. (2025), who found that back-vowel contexts tend to require more complex articulatory coordination in post-stroke patients. Thus, the dhammah /u/ variation can be seen as a prominent phonetic environment in showing impaired synchronization between tongue and lip movements in the production of the phoneme ر[*r*] (Nurfitri et al., 2025).

Table 3
Recapitulation of Phoneme Parameters ر [*r*] in the Harakat *Fathah, Kasrah,* and *Dhammah* Variations between SMRA and PSP

Parameter	/ra/ (Fathah)	/ri/ (*Kasrah*)	/ru/ (Dhammah)
SMRA Duration	0.356 seconds	0.242 seconds	0.198 seconds
PSP Duration	0.406 seconds	0.163 seconds	0.333 seconds
Difference in duration	+14.1% (longer)	-32.6% (shorter)	+68.2% (longer)
F0 SMRA	± 244.3 Hz	± 209.4 Hz	± 80.24 Hz
F0 PSP	± 138,4 Hz	± 103,6 Hz	± 140,9 Hz
Intensity SMRA	± 69,74 dB	± 70,83 dB	± 69,67 dB
Intensity PSP	± 64,05 dB	± 66,11 dB	± 74,69 dB

Table 3 presents a summary of the acoustic parameters of the phoneme ر[ɾ] in three vowel variations, namely *fathah* /ra/, *kasrah* /ri/, and *dhammah* /ru/, based on SMRA data as a reference for fluent pronunciation and PSP as the research subject. In general, the results show that sound production by PSP experiences changes in duration, fundamental frequency, and intensity in each vowel context. In the *fathah* variation, the sound duration tends to be longer, accompanied by a decrease in F0 and intensity. In the *kasrah* variation, the duration is actually shorter with a decrease in F0 and lower sound energy. Meanwhile, the *dhammah* variation shows the greatest lengthening of duration, accompanied by an increase in F0 and intensity compared to the reference pattern. These findings indicate that differences in vowel influence the articulatory realization of the phoneme ر[ɾ], and show that the back vowel context /u/ appears to be the most challenging phonetic environment for PSP in maintaining stable sound production.

These findings reinforce the principles of Articulatory Phonetics proposed by Ladefoged (2015), namely that changes in articulatory mechanisms produce phonetic consequences that can be observed in acoustic parameters. In the present study, variations in the characteristics of the phoneme ر [ɾ] across different vowel diacritics indicate that neuromotor impairments resulting from ischemic stroke affect not only the general ability to produce speech sounds but also the coordination of the articulatory organs according to the demands of sound production in each specific vowel context (Karia, 2023; Llico et al., 2023). These findings further support the view that articulatory impairment in stroke survivors is context-dependent, meaning that the degree of impairment may vary depending on the articulatory configuration required in each vowel environment. Thus, the acoustic changes identified in this study do not merely reflect general motor impairment but also demonstrate that different articulatory demands can result in distinct patterns of impairment. Therefore, the findings provide empirical evidence that the relationship between tongue movement and the acoustic characteristics of the phoneme ر [ɾ] can be effectively explained within the framework of Articulatory Phonetics.

From the perspective of Arabic phonetics, these findings indicate that differences in vowel diacritics may affect the degree of difficulty in producing the phoneme ر [ɾ] in individuals with post-ischemic stroke. This phoneme belongs to the category of *ḥurūf al-lisān*, or tongue consonants, whose production relies heavily on the precise movement of the tongue tip. Consequently, impairments in motor coordination may result in different acoustic characteristics across different vowel environments. Accordingly, analyzing this phoneme across the three vowel diacritics *fatḥah*, *kasrah*, and *ḍammah* provides a more detailed perspective than an analysis that examines articulatory impairment only in general terms. These findings are also consistent with developments in clinical neurolinguistics and cross-linguistic dysarthria research, which indicate that the phonological structure of each language influences the characteristics of speech impairment. Unlike previous studies that have generally focused on vowel production, stop consonants, or acoustic measurements of speech, the present study demonstrates that variations also influence the characteristics of a specific Arabic phoneme in vowel context. This finding, therefore, extends the scope of dysarthria research into Arabic phonetics, a domain that remains relatively underexplored.

This study also offers a new perspective by demonstrating that acoustic-phonetic analysis of Qur'anic recitation can be used as an objective approach to identifying articulatory characteristics in individuals with post-ischemic stroke. The use of Surah Al-Qāri'ah as a controlled phonetic corpus allows each phoneme to be analyzed within a consistent linguistic context, thereby facilitating the interpretation of the acoustic variations

identified. The novelty of this study lies in its analysis of the phoneme ر[*r*], as one of the *ḥurūf al-lisān*, across the vowel diacritics of *fatḥah*, *kasrah*, and *ḍammah* in Qur'anic recitation, using an acoustic phonetic approach as the basis for interpreting articulatory impairment in patients following ischemic stroke. This focus distinguishes the present study from previous studies that have predominantly examined general speech acoustic parameters or focused on clinical assessment without investigating the influence of phonological context on the realization of a specific phoneme. The findings demonstrate the potential of Praat-based acoustic analysis as a complementary tool for speech rehabilitation assessment and provide a basis for future research involving larger numbers of participants, a broader range of *ḥurūf al-lisān*, and different levels of stroke severity.

4. CONCLUSION

The findings of this study indicate that the production of the phoneme ر[*r*] in an individual with post-ischemic-stroke dysarthria exhibits varying acoustic characteristics across different vowel contexts, namely *fatḥah*, *kasrah*, and *ḍammah*. These variations are reflected in differences in duration, fundamental frequency (F0), intensity, and formant stability, indicating that neuromotor impairment does not affect articulation uniformly but rather depends on the articulatory demands required to produce each vowel-diacritic variation. These findings suggest that articulatory impairment affecting Arabic phonemes, particularly the phoneme ر [*r*], is context-dependent, such that analysis based on vowel context can provide more detailed information than a general evaluation of articulation. Thus, this study contributes to the field of Arabic phonetics from a clinical neurolinguistic perspective by applying acoustic phonetic analysis to Qur'anic recitation as a controlled phonetic corpus. Based on these findings, changes in the acoustic characteristics of the phoneme ر [*r*] show potential for use as one of the phonetic indicators for identifying post-stroke articulatory impairment. However, given that this study involved only one participant, these findings should be regarded as preliminary and require further validation through studies involving larger numbers of participants and varying levels of stroke severity. Therefore, future research is recommended to examine the consistency of context-dependent patterns of articulatory impairment in other *ḥurūf al-lisān* phonemes, thereby providing a stronger empirical basis for the development of objective assessment tools and speech therapy interventions grounded in Arabic phonetics.

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Authors' Contribution
Muhammad Arifin Ilham developed the main research concept, conducted the analysis, and wrote the manuscript. Rinaldi Supriadi contributed to directing the research framework and refining the analytical

approach. Mohamad Zaka Al Farisi supervised the research process and provided academic guidance throughout the study. Hanifah Nurfitri assisted in collecting and preparing the research data.

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