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AGE-RELATED ARTICULATORY VARIATIONS OF ARABIC /dˤ/: ACOUSTIC ANALYSIS IN ELDERLY NON-NATIVE SPEAKERS

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Abstract

Age-related decline in speech motor control affects older adults' ability to pronounce Arabic phonemes accurately. While prior studies examined working-age native speakers, this study addresses non-native older adults to map the specific articulatory challenges they face in pronouncing /dˤ/ and investigate aging's effect on acoustic stability. We employed descriptive and comparative phonetic analysis, evaluating four older adults (ages 51–73) with varying educational backgrounds (Islamic boarding, elementary, junior high, and senior high schools). Data were acoustically compared to native speaker standards using Praat software to measure the duration, fundamental frequency, intensity, and formant patterns of /dˤ/ in initial, medial, and final word positions. Findings indicate that Islamic boarding school education does not ensure later-life articulatory precision; rather, overcompensation led to velarization failure due to prolonged articulation. In contrast, participants with junior and senior high school backgrounds produced acoustic qualities closer to native speakers. Although motor limitations restrict airflow endurance, cognitive retention of articulation points remains well-preserved. Ultimately, none of the elderly participants matched native speaker standards due to physiological decline rather than phonological memory loss. Consequently, evaluations of elderly Quranic recitation should emphasize articulation point accuracy rather than energetic performance.

Keywords: acoustic phonetics; /dˤ/ phoneme; phonetic analysis; older adults; Praat.

1. Introduction

Accurate pronunciation of Arabic sounds is essential for proper Quranic recitation. Linguistic accuracy serves as a primary prerequisite to ensure the Quran's meaning is conveyed clearly to readers and listeners. As emphasized by Al Farisi (2023), the acceptability of a Quranic text, whether in the form of translation or oral transmission, is highly contingent upon aspects of accuracy and clarity; consequently, even the slightest deviation at the phonetic level can impede the delivery of the intended meaning within the source text.

The ability to accurately pronounce Arabic phonemes in accordance with established phonetic rules is a fundamental aspect of Arabic language learning. Pronunciation errors not

only affect articulation but also potentially induce semantic shifts, which in turn impact the quality of comprehension and the solemnity of worship (Maulani & Alwan, 2023; Nasikin et al., 2023). A profound understanding of phonetic sounds and pronunciation rules is crucial for accurate communication in Quranic recitation (Maskuri et al., 2023; Musthofa et al., 2024).

Articulatory inaccuracies often lead to phonetic errors such as vowel mispronunciation, incorrect duration, or consonant substitution. These errors can significantly alter word meanings. Examples include the failure to distinguish between the letters ص and س or between خ and غ (Jamil & Maulidah, 2023). These difficulties generally emerge with hijaiyah (Arabic alphabet) letters that lack equivalents in the Indonesian language, particularly specific consonant groups such as ع, ق, ص, ش, ذ, خ, ث, ض, ظ, ط, and غ (Nurshafnita & Zainuddin, 2023). Therefore, the study of phonetics *('ilm al-aṣwāt)* serves as the primary foundation to ensure that Arabic pronunciation occurs accurately and according to phonetic rules.

Phonetic analysis provides an objective basis for identifying phonetic errors that frequently arise in Arabic language learning. Phonemic deviations, such as impaired vowel quality, durational differences, and consonant substitutions, have direct implications for semantic shifts. This phenomenon is particularly evident in the pronunciation of *hijaiyah* letters that possess specific articulatory characteristics not found in the Indonesian phonological system, such as emphatic consonants (ص, ض, ظ, ط) and guttural consonants (ع, غ, خ). The identification of these inaccuracies serves as the initial step in systematically mapping pronunciation barriers, as highlighted in the aforementioned studies (Nurshafnita & Zainuddin, 2023).

Prior studies have extensively examined Arabic pronunciation errors in students and working-age populations, often focusing on mother tongue interference and instructional methods (Ali et al., 2023; Musthofa et al., 2024; Rifai & Suharto, 2020). Specifically, the /dˤ/ phoneme demonstrates a higher degree of complexity than other Arabic phonemes. A study by El-Khaissi (2022) investigated whether the vowel compensation strategy (emphatic spreading) often employed by advanced learners to navigate the pronunciation difficulties of the /dˤ/ phoneme also occurs in older adults who possess different articulatory motor capabilities. This study addresses the gap by analyzing the articulatory complexity and acoustic distortion of /dˤ/ among older non-native learners, offering a novel focus on /dˤ/ pronunciation errors among older adults, an underexplored demographic in Quranic phonological research. While previous research, such as Kalaldeh and Al-Shdaifat (2019), focused on working-age native speakers, the phonetic challenges faced by elderly learners remains underexplored.

Although numerous phonemic error studies have been conducted on students (santri), university students, and speakers from specific linguistic backgrounds, research specifically highlighting older adults remains relatively limited. This limitation exists because older adults possess distinct physiological characteristics compared to other age groups, such as decreased elasticity of the tongue muscles, weakened coordination of the articulatory organs, and reduced concentration, all of which have the potential to significantly affect the precise pronunciation of Arabic phonemes (Muliatno, 2023; Sholihin, 2020).

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In Low- and Middle-Income Countries (LMICs) such as Indonesia, the older adult population is defined as individuals aged 50 years and older, reflecting an earlier onset of age-related physiological changes linked to a lower life expectancy compared to high-income nations (Lestari et al., 2019). While extensive research has been conducted on the /dˤ/ phoneme, previous literature is predominantly dominated by analyses of native speakers within the working-age demographic. Therefore, the present study expands upon the existing literature by focusing specifically on non-native older adults. This particular phoneme demands significant tongue dominance and entails high articulatory complexity, making it highly susceptible to sound substitution. This is especially true for older speakers due to the previously mentioned physiological changes. Thus, there is a distinct need for research that specifically identifies and analyzes the errors associated with the /dˤ/ phoneme among older adults, utilizing native speaker pronunciation as the standard benchmark.

For the purposes of this study, *majelis taklim* a form of non-formal Islamic education was selected as it serves as the primary avenue for older adults to learn and refine their Quranic recitation. Its flexible and accessible learning characteristics, coupled with a predominantly older demographic, render *majelis taklim* a highly appropriate context for observing phonologica errors in the pronunciation of *hijaiyah* letters. Several studies have indicated that the effectiveness of Quranic learning for older adults in *majelis taklim* can be enhanced through the application of suitable instructional methods, such as the Iqra method, repetition, andragogical approaches, and the Tsaqifa method (Munirah, 2023; Ni'mah et al., 2025).

This research presents a distinct novelty by focusing the analysis on the errors of the /dˤ/ phoneme among older adults, a demographic that remains significantly underexplored within Quranic phonological research utilizing acoustic analysis. Against this backdrop, the primary objective of this study is to map and analyze the articulatory challenges of the /dˤ/ phoneme in older adults, specifically examining how the physiological processes of aging influence the stability of the produced sounds, as measured and evaluated through Praat software.

2. Literature Review

Prior studies show that phonetic errors, including phonetic alterations and sound shifts, remain prevalent among Arabic learners (Ali et al., 2023). This phenomenon is influenced by mother tongue interference, as well as other internal and external factors (Musthofa et al., 2024; Rifai & Suharto, 2020). From the perspective of text acceptability, acoustic accuracy is essential to prevent semantic distortion, particularly in sacred texts (Al Farisi, 2023). Specifically, the /dˤ/ phoneme exhibits a higher degree of articulatory complexity compared to other phonemes. El-Khaissi (2022) investigated vowel compensation strategies employed to navigate the pronunciation difficulties of /dˤ/ among speakers with articulatory motor limitations. This study addresses the gap by analyzing /dˤ/ pronunciation among older non-native learners, a group rarely examined in prior research (Kalaldeh & Al-Shdaifat, 2019).

2.1 Physiological Characteristics and Articulatory Disorders in Older Adults

Older adults exhibit physiological characteristics distinct from other age groups, such as decreased elasticity of the tongue muscles, weakened coordination of articulatory organs, and reduced concentration capabilities. Muliatno (2023) and Sholihin (2020) elucidate that these physical conditions have the potential to significantly impact the precise pronunciation of hijaiyah letters. In Low- and Middle-Income Countries (LMICs) like Indonesia, older adults are classified from the age of 50 and above, aligning with the earlier onset of these physiological declines due to a lower average life expectancy (Lestari et al., 2019). This functional decline results in disrupted sound transitions and reduced acoustic stability compared to native speakers.

2.2 The Articulatory Complexity of the /dˤ/ Phoneme

According to Aldamen and Al-Deaibes (2023), the /dˤ/ phoneme possesses high articulatory complexity as it involves a secondary articulation mechanism. This characteristic demands dominant tongue motor control; thus, in older speakers, this complexity potentially triggers sound substitution corresponding with the decline in articulatory function. The /dˤ/ phoneme requires secondary articulation involving lateral tongue edges against upper molars, producing emphatic resonance (Marlina, 2019; Ulpah et al., 2025). Failure to produce emphatic resonance is marked by weakened spectral features in the formant patterns (Alihuddin et al., 2022).

2.3 Acoustic Phonetics as an Objective Evaluation Instrument

This study is novel in applying Praat-based acoustic analysis to older adults' Quranic recitation. Ghani et al. (2024) state that acoustic analysis can provide a more accurate representation of pronunciation segmentation characteristics compared to subjective assessments alone. Praat measures duration, frequency, and formant patterns to objectively evaluate recitation accuracy.

2.4 The Context of Andragogical Learning in *Majelis Taklim*

Majelis taklim provides a flexible learning environment for older adults, where andragogical methods such as repetition and Iqra enhance pronunciation refinement (Munirah, 2023). Considering the existing physiological barriers, Ni'mah et al. (2025) emphasize the importance of instructional guidance that incorporates an andragogical perspective, ensuring that the process of pronunciation refinement does not induce mental pressure on older adults. Consequently, this research contributes to the existing literature by providing an objective, Praat-based acoustic evaluation of /dˤ/ pronunciation challenges, specifically tailored to the physiological and andragogical contexts of older learners.

3. Research Method

This study employed descriptive and comparative methods within a content analysis design to describe and evaluate /dˤ/ pronunciation among older adults at the Miftahul Amanah *majelis taklim*. The acoustic characteristics of recitations from selected Surahs in *Juz* 30 were analyzed using Praat software. The results were subsequently compared with native speaker pronunciation standards to establish a baseline for evaluating articulatory accuracy. Pronunciations were compared to a native speaker benchmark (Kaltoum Zerrad, Moroccan

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qāri'ah). Purposive sampling was applied to select respondents meeting specific criteria (Berndt, 2020).

Table 1.
Research Sample Profile

Indicator	Sample Profile
Gender	Female
Age	≥ 50 years
Educational background	1. Elementary school graduate 2. Junior high school graduate 3. Senior high school graduate 4. Islamic boarding school graduate
Name	Majelis taklim miftahul amanah
Native speaker	Kaltoum zerrad, moroccan qāri'ah

Description:
NS : *Native Speaker*
R1 : Respondent with Elementary School background
R2 : Respondent with Junior High School background
R3 : Respondent with Senior High School background
R4 : Respondent with Islamic Boarding School background

Table 2.
Position of the /dˤ/ Phoneme within Words

Letter	Position		
	Initial	**Medial**	**Final**
ض	ضَاحِكَةٌ (Surah 'abasa: 39)	تَضْلِيلٍ (Surah al-fiil: 2)	وَٱلْأَرْضَ (Surah an-nazi'at: 30)

3.1 Data Collection Techniques

Data collection was conducted by recording the respondents' recitations of selected Quranic verses containing the /dˤ/ phoneme. This specific phoneme was selected because it represents a sound frequently subject to phonetic errors among non-native Arabic learners due to its lack of a phonological equivalent in Indonesian (Fudhaili et al., 2023). Although the /dˤ/ phoneme requires complex apico-dental articulation, these elements were strictly analyzed through acoustic parameters rather than subjective observation. The recorded data were processed using Praat software (version 6.4.26), where spectrograms were used to analyze key phonetic features, specifically sound duration, fundamental frequency, and intensity (Al Farisi et al., 2025; Ghani et al., 2024).

3.2 Data Analysis Techniques

Praat analysis compared the respondents' /dˤ/ pronunciation with native speaker standards, focusing on duration, frequency, and formant patterns. This comparison aimed to identify age-related articulatory influences on /dˤ/ pronunciation among the older adults. As the final step, the data were transcribed into International Phonetic Alphabet (IPA) symbols

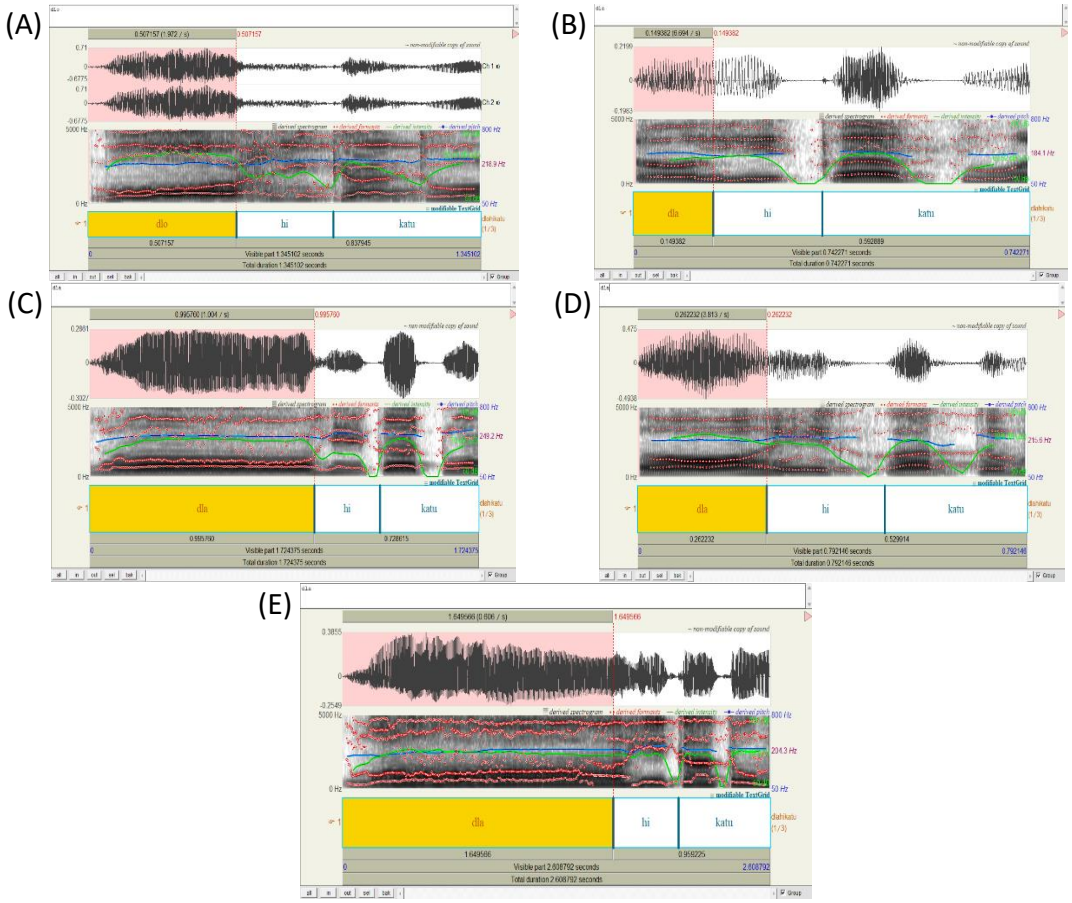
(Brierley & Heselwood, 2022). This transcription step ensured an objective representation of phonetic accuracy relative to the reference standard.

4. Results and Discussion

The acoustic analysis of the /dˤ/ phoneme among older adult respondents revealed distinct articulatory patterns when compared to the NS benchmark. Evaluated through Praat spectrograms, the data highlight varying degrees of phonetic accuracy and sound distortion across different word positions. Rather than detailing each spectrogram individually, the following subsections synthesize the primary articulatory challenges specifically concerning duration, formants (F1-F2 narrowing), and intensity to evaluate the impact of age-related physiological changes and educational background on emphatic consonant production.

4.1 Acoustic Interference of the /dˤ/ Phoneme in Word-Initial Position

Figure 1-5.
Spectrogram Visualizations of /dˤ/ in Initial Position across Respondents



Note. NS = Native Speaker, R = Respondent. (A) NS. (B) R1. (C) R2. (D) R3. (E) R4.

As summarized in Table 3, the acoustic realization of the /dˤ/ phoneme in the word-initial position reveals significant articulatory variations among the older adult respondents compared to the NS. The primary acoustic marker for the /dˤ/ phoneme's emphatic resonance is velarization, indicated by the narrowing distance between the first (F1) and second (F2) formants (Aldamen & Al-Deaibes, 2023). The NS demonstrated optimal

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articulatory control, establishing a benchmark duration of 0.507 seconds and a distinct F1-F2 narrowing, reflecting highly stable secondary articulation. Instead of repeating these foundational acoustic concepts for each recording, this benchmark serves as the primary metric for evaluating the respondents articulatory precision.

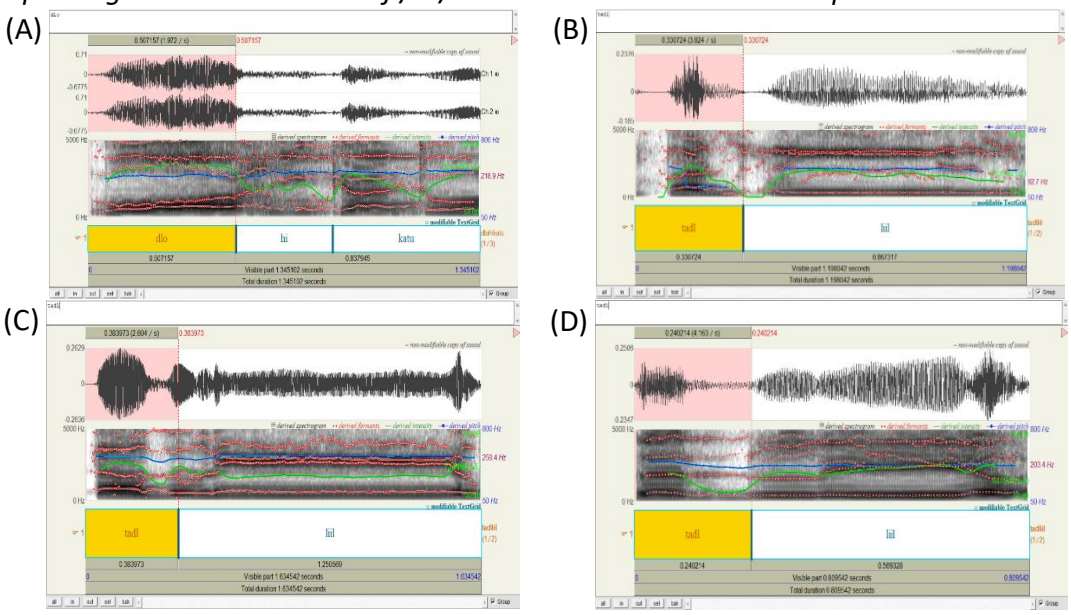
Figures 2 through 5 illustrate the contrasting acoustic outputs of the four respondents. Notably, respondents with general education backgrounds (R2 and R3) produced acoustic characteristics closest to the NS benchmark. Despite their shorter articulatory durations (0.995s and 0.262s, respectively), both maintained coherent F1-F2 narrowing and stable intensity. This pattern indicates preserved phonological memory and efficient airflow control. Conversely, R4 despite having an Islamic boarding school background, exhibited severe articulatory overcompensation. As seen in Figure 5, R4 excessively prolonged the articulation to 1.649 seconds. While the acoustic energy was dense, this prolonged duration disrupted the natural resonance, demonstrating that excessive articulatory effort does not equate to phonetic precision.

This comparative evidence highlights a critical intersection between physiological aging and linguistic background. R4's overcompensation likely reflects a deliberate attempt to bypass age-related physiological constraints such as decreased tongue muscle elasticity through brute force, ultimately resulting in velarization failure (Muliatno, 2023; Sholihin, 2020). In contrast, the stability observed in R2 and R3 suggests that while the physiological degradation of articulatory organs restricts airflow endurance, the cognitive retention of the articulation point (*makhraj*) remains intact. Therefore, phonetic inaccuracies in older adults in this position stem primarily from motor control limitations rather than a loss of phonological knowledge. From a pedagogical perspective, this implies that instructional methods for older adults should emphasize the precision of articulation points rather than demanding prolonged absolute energetic perfection (Munirah, 2023; Ni'mah et al., 2025).

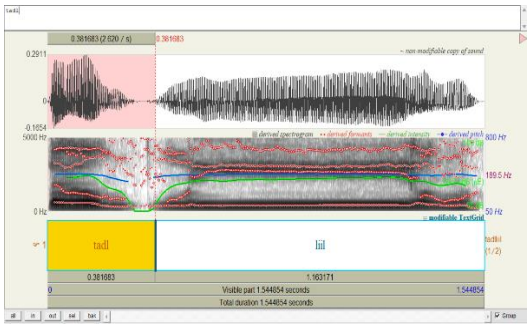
4.2 Acoustic Interference of the /dˤ/ Phoneme in Word-Medial Position

Figure 6-10

Spectrogram Visualizations of /dˤ/ in Medial Position across Respondents



(E)



Note. NS = Native Speaker, R = Respondent. (A) NS. (B) R1. (C) R2. (D) R3. (E) R4.

In the word-medial position, the articulatory challenge shifts from initiating the emphatic sound to executing a smooth transition into the subsequent long vowel "*liil*". As detailed in Table 3, the NS benchmark for this position established a duration of 0.433 seconds with a fluid pitch contour and distinct F1-F2 narrowing. Unlike the highly variable outputs observed in the word-initial position, Figures 7 through 10 demonstrate that the phonetic environment of a medial position facilitates significantly greater articulatory consistency among all older adult respondents. The acoustic data reveals that R1, R2, R3, and notably R4, all successfully maintained the requisite F1-F2 narrowing that signifies proper velarization. Although minor fluctuations in intensity during the airflow closure phase were observed (particularly in R3 and R4), the subsequent transition to the vowel segment effectively stabilized their acoustic resonance, a phenomenon consistent with the acoustic correlates of energy transition and plosive voicing (Misnadin & Kirby, 2020).

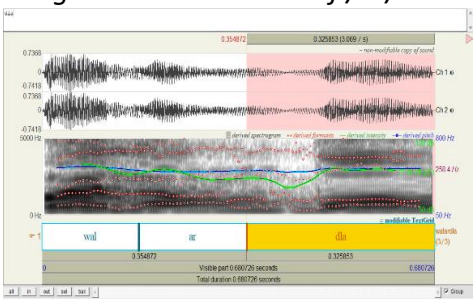
This uniformity suggests that being flanked by vowels provides a phonetic "anchor" that assists the aging articulatory organs in managing complex secondary articulations. Even R4, who struggled with overcompensation in the initial position, produced a controlled duration (0.381s) and clear emphatic resonance when aided by the momentum of the surrounding vowels. From a pedagogical standpoint, this finding carries a significant implication for andragogical Quranic instruction: when introducing complex emphatic consonants to older adults, educators should initiate practice within vowel-flanked medial positions rather than isolated or initial positions. This approach leverages the phonetic environment to bypass motor control limitations, thereby facilitating a smoother and less physically demanding learning process (Ni'mah et al., 2025).

4.3 Acoustic Interference of the /dˤ/ Phoneme in Word-Final Position

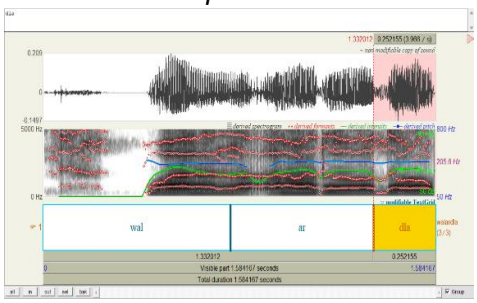
Figure 11-15.

Spectrogram Visualizations of /dˤ/ in Final Position across Respondents

(A)



(B)



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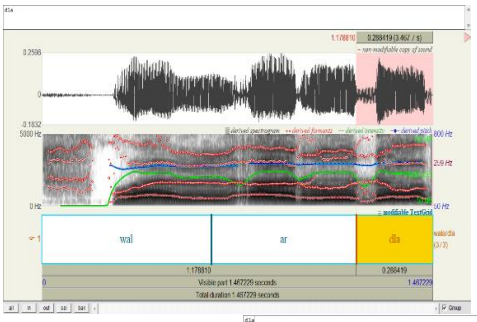
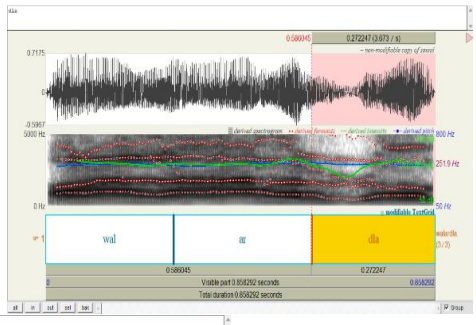
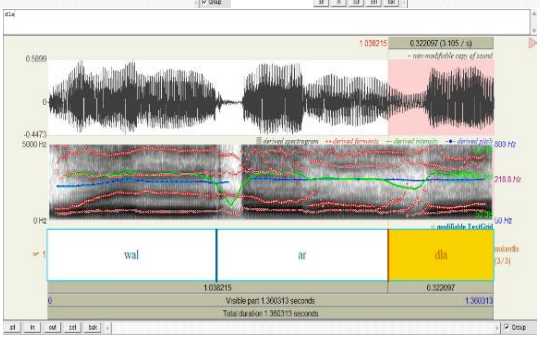
(C)



(D)



(E)



Note. NS = Native Speaker, R = Respondent. (A) NS. (B) R1. (C) R2. (D) R3. (E) R4.

Concluding an utterance with the /dˤ/ phoneme alters the articulatory dynamics, shifting the demand toward sustaining the emphatic resonance as the airflow ceases. As indicated in the summary data in Table 3, the NS maintained a stable duration of 0.325 seconds with a sharp F1-F2 narrowing, demonstrating optimal articulatory stamina at the end of the utterance. When comparing the respondents, Figures 12 through 14 reveal that R1, R2, and R3 successfully retained this phonetic trait, exhibiting consistent F1-F2 narrowing and stable intensity. This indicates that their articulatory control remained intact through the final phase of the word. Conversely, R4 once again exhibited notable phonetic distortion. While R4's duration (0.322s) closely matched the NS, the acoustic spectrogram Figure 15 displayed a distinct lack of sharpness and a widening F1-F2 distance (F2 rising to 1300–1400 Hz), which is visual evidence of an imperfect velarization process and weakened spectral features (Alihuddin et al., 2022).

This acoustic failure in the final position provides a crucial interpretive insight regarding the physiological constraints of older adults. While the medial position provided a phonetic "anchor" through flanking vowels, pronouncing an emphatic consonant at the end of a word requires independent muscular retention to halt the airflow while simultaneously elevating the tongue root. R4's inability to maintain this dual-action suggests the presence of articulatory fatigue a natural consequence of aging where the stamina of the articulatory organs diminishes at the end of an utterance (Muliatno, 2023; Sholihin, 2020). Pedagogically, these findings suggest that when older adults recite Quranic verses, evaluators and instructors should anticipate end-of-word articulatory fatigue. Instructional focus should therefore prioritize the accuracy of the initial point of articulation (makhraj) rather than demanding absolute, sustained energetic perfection at the end of phrases, which may be physiologically unattainable for the elderly (Hidayat, 2022; Maulana Haryadi & Marlina, 2025).

Table 3.
Acoustic Analysis Results Table

Respondent	Phoneme Position	Duration (s)	Pitch (Hz)	Intensity (dB)	F1	F2
NS	Initial	0.507	218.9	82.43	500-600	1050–1150
	Medial	0.433	266.7	74.84	550-600	1100–1200
	Final	0.325	258.4	77.56	500-600	1100–1200
R1	Initial	0.149	184.1	69.62	600-700	1150–1250
	Medial	0.330	92.7	57.29	600-700	1100–1200
	Final	0.211	205.6	69.11	500-600	1050–1150
R2	Initial	0.995	249.2	76	500-600	1050–1150
	Medial	0.383	259.4	73.33	500-600	1050–1150
	Final	0.288	259.0	71.76	500-600	1150–1250
R3	Initial	0.262	215.0	788	500-600	1100–1200
	Medial	0.240	203.4	64.09	500-600	1000–1100
	Final	0.322	251.9	78.65	500-600	1100–1200
R4	Initial	1.649	204.3	74.24	500-600	1050–1150
	Medial	0.381	189.5	69.74	450-550	1000–1100
	Final	0.322	251.9	76.91	600-700	1300–1400

5. Conclusion

This study is novel in applying acoustic analysis to elderly non-native learners, an underexplored demographic in Quranic phonology. Praat analysis confirmed native speakers' stability across all acoustic parameters of the /dˤ/ phoneme. Conversely, age-related physiological decline significantly disrupts articulatory stability among older adults. Acoustic analysis revealed that *pesantren* education did not ensure native-like precision in later life. In fact, *pesantren* graduates frequently showed articulatory overcompensation, leading to distorted resonance. On the other hand, despite neurological constraints, learners with general educational backgrounds often demonstrated near-native precision. This contrast suggests that articulatory motor memory persists longer than muscular endurance. Ultimately, age-related physiological decline outweighed the benefits of prior religious training.

Pedagogically, the findings of this study offer crucial recommendations for andragogical Quranic instruction. Instruction for elderly learners should prioritize articulation point accuracy and adapt to physical limitations. Evaluators and instructors at *majelis taklim* should prioritize the precision of initial articulation points (*makhraj*) over demanding prolonged, absolute energetic perfection, which is often physiologically unattainable for the elderly. To bypass motor control limitations and articulatory fatigue, educators are advised to initiate the practice of complex emphatic consonants within vowel-flanked medial positions. This phonetic environment provides an 'anchor' that facilitates a smoother and less physically demanding learning process for older adults. Broadly, these findings contribute to phonetic research on aging and inform pedagogical strategies in non-formal Islamic education.

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