

Gender and ATR vowel space in Dholuo

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Abstract

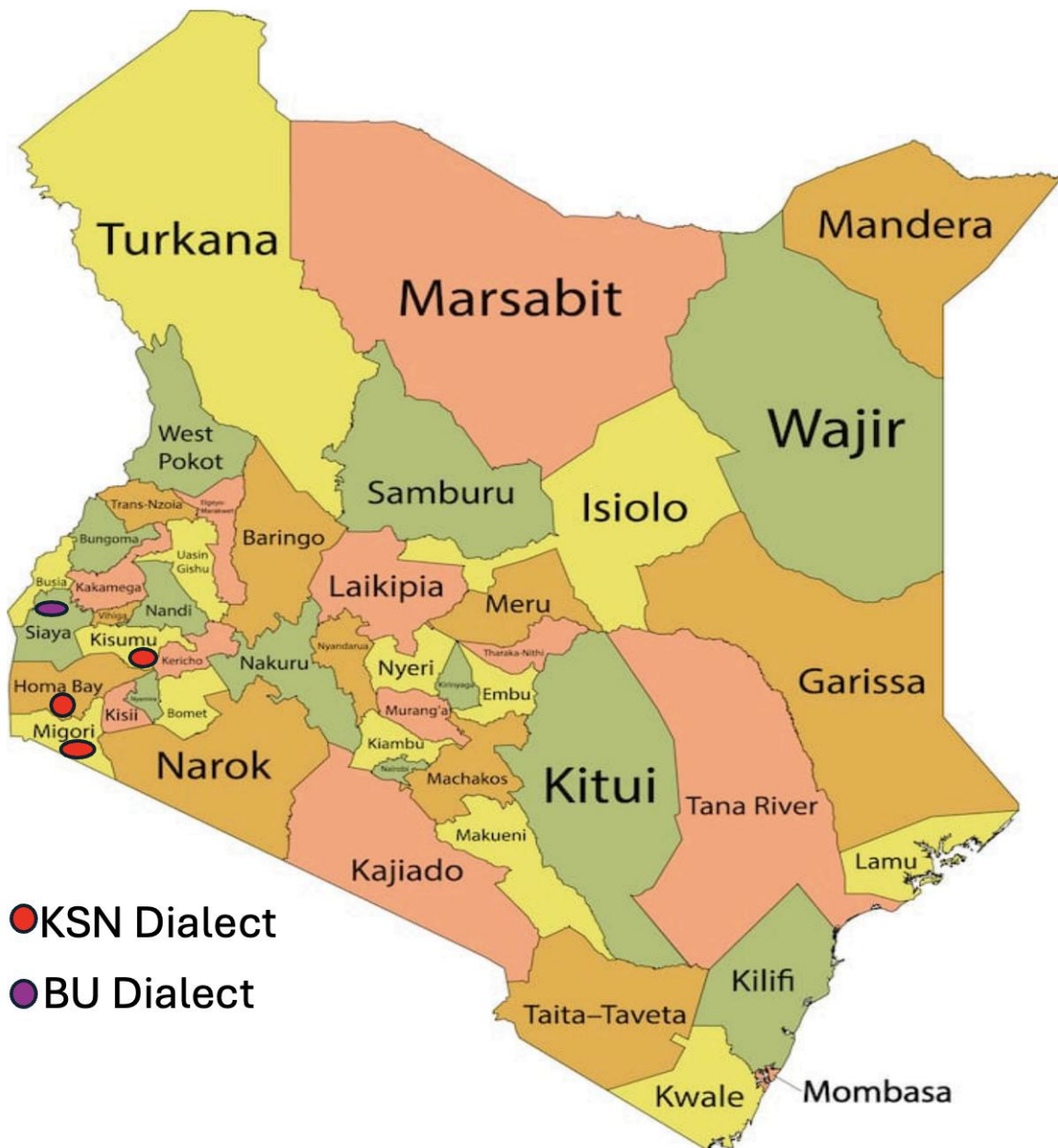
This paper investigates the acoustic realization of Advanced Tongue Root (ATR) vowel contrasts in Dholuo, with particular attention to gender-conditioned variation in vowel production. Using Lobanov-normalized formant measurements (F1 and F2), the study analyzes speech data from eight native speakers (four female and four male) representing two dialect regions, Kisumu South Nyanza (KSN) and Boro-Ukwala (BU). The analysis focuses on the distribution of the nine Dholuo vowels in acoustic space and the realization of four ATR vowel pairs (/i–ɪ, e–ɛ, o–ɔ, u–ʊ/), with /a/ treated as neutral. To assess the reliability of observed acoustic differences, analyses of variance (ANOVA) were conducted on normalized F1 values across vowel categories and speaker groups. The results show that ATR contrasts are consistently reflected in the acoustic data, with [+ATR] vowels exhibiting lower F1 values than their [–ATR] counterparts. The statistical analysis confirms that these differences are significant across the vowel inventory and that both vowel category and gender contribute to variation in F1, with a significant interaction between the two factors. This pattern is particularly robust in the female data, where clear separation is observed across all vowel pairs. In the male data, ATR distinctions are generally maintained but show reduced consistency, especially in the high front pair /i–ɪ/, where the expected pattern is weakened. Vowel space analysis further indicates that female speakers produce more clearly differentiated vowel categories, while male speakers exhibit greater dispersion and overlap in certain regions of the acoustic space. Overall, the findings provide phonetic evidence for the acoustic implementation of ATR contrasts in Dholuo, demonstrating that while the contrast is systematically maintained, its acoustic realization varies across vowel pairs and speaker groups.

1. Introduction

Advanced Tongue Root (ATR) distinctions constitute a central feature of vowel systems in many African languages and have been widely studied from both phonological and phonetic perspectives. In such systems, vowels are organized according to the position of the tongue root, with [+ATR] vowels involving pharyngeal expansion and [–ATR] vowels involving a more constricted configuration (Creider & Hall 1998). These articulatory differences are typically reflected acoustically in the first formant (F1), which tends to be lower for [+ATR] vowels (Casali 2003, 2008). While this relationship is well established cross-linguistically, less is known about how consistently ATR contrasts are realized across speakers within individual languages and how their acoustic implementation may vary across speaker groups. This study addresses this issue by examining the acoustic realization of ATR contrasts in Dholuo, with particular attention to gender-conditioned variation and vowel space organization.

Dholuo is a Western Nilotic language belonging to the Nilotic branch of the Nilo-Saharan language family (Greenberg 1963). It is spoken by approximately five million people in Kenya,

primarily in the western region surrounding Lake Victoria (Kenya National Bureau of Statistics [KNBS] 2019). Within the broader Luo language cluster, Dholuo is closely related to languages such as Acholi, Padhola, and Alur spoken in Uganda, as well as Shilluk and Bor spoken in South Sudan (Omondi 2020), which share typological features including similar vowel systems and the presence of ATR distinctions. In Kenya, Dholuo exhibits regional dialectal variation. Oduol (1990) identifies two major dialect regions: the Boro-Ukwala (BU) dialect, spoken primarily in Siaya County, and the Kisumu South Nyanza (KSN) dialect, spoken in Kisumu, Homa Bay, Migori, and parts of Siaya counties. Although the dialects are mutually intelligible, native speaker intuitions and linguistic observations suggest the presence of phonetic differences between them. Map 1 illustrates the approximate distribution of the Luo-speaking area in western Kenya and the locations of the BU and KSN dialect regions.



Map 1. Geographic distribution of the BU and KSN dialect areas (adapted from Rodic 2021)

Phonological descriptions of Dholuo generally identify a nine-vowel system organized around ATR distinctions. In this system, four vowel pairs contrast for the feature $[\pm\text{ATR}]$, typically represented as $/i-i/$, $/e-\varepsilon/$, $/o-\text{o}/$, and $/u-u/$, together with the low vowel $/a/$, which lacks a corresponding $[\text{+ATR}]$ counterpart and is therefore often treated as neutral (Okombo 1982; Oduor 2002; Swenson 2015; Owego 2025). As illustrated in Figure 1, the vowel system is arranged according to articulatory position: high vowels appear at the top of the chart, low vowels at the bottom, and front–back distinctions are represented horizontally. The paired vowels occupy similar positions in the system but differ in tongue-root advancement, which defines the $[\pm\text{ATR}]$ contrast. The Dholuo vowel system is therefore represented as follows.

$[\text{+ATR}]$		$[\text{-ATR}]$	
i	u	ɪ	ʊ
e	o	ɛ	ɔ
		a	

Figure 1. $[\pm\text{ATR}]$ vowels in Dholuo (adopted from Swenson [2015])

Previous studies of Dholuo vowels have examined aspects of vowel space organization and dialectal variation (Stafford 1967; Okombo 1982; Oduor 1990; Odawa 2004; Njuki 2016). These studies show that vowels belonging to the two ATR sets generally occupy different regions of the acoustic space, indicating that the contrast is reflected in phonetic patterns. However, they do not systematically evaluate how strongly these vowel categories are separated within the acoustic space or how consistently this separation is maintained across speakers. It remains unclear whether examining the full vowel space (i.e., the combined F1–F2 distribution of vowels) provides additional insight into the organization and robustness of ATR contrasts beyond what can be observed through F1 comparisons alone. This study therefore extends previous work by analyzing not only the presence of ATR-related differences, but also how these contrasts are structured and distributed within the vowel space.

In addition to dialectal variation, variation in vowel production may also arise from speaker-related factors. While the preceding discussion has focused on language-internal variation in Dholuo, sociophonetic research shows that vowel systems can also vary systematically across speaker groups due to both physiological and social influences (Labov 2006). Gender has been shown to influence vowel space organization, with female speakers often producing more dispersed and clearly differentiated vowel categories than male speakers (Ladefoged & Johnson 2015; Jacewicz, Fox & Salmons 2009). The relevance of gender in the present study is therefore not specific to ATR systems alone but reflects a broader pattern of variation in vowel production. Examining whether such differences are also observable in Dholuo makes it possible to evaluate how consistently ATR contrasts are realized across speakers.

Despite the well-established phonological description of the Dholuo vowel system, there remains limited acoustic evidence on how ATR contrasts are realized across speakers and how consistently these contrasts are maintained across vowel pairs. While previous studies have shown that ATR vowels occupy distinct regions of the acoustic space, they do not evaluate the degree of separation between vowel categories or how this separation varies across speaker groups. It is unclear whether vowel space representations provide additional insight into the strength and organization of ATR contrasts beyond single-formant analyses, or whether they simply reproduce patterns already observable in F1. Addressing this question is crucial for understanding how phonological contrasts are implemented in actual speech production. This study therefore combines normalized formant analysis with vowel space modeling to examine both the acoustic realization of

ATR contrasts and their organization across male and female speakers. The study addresses the following objectives:

1. To examine the acoustic realization of ATR vowel contrasts in Dholuo using normalized formant measurements.
2. To investigate whether the distribution of ATR vowel pairs in the acoustic vowel space differs between male and female speakers.
3. To evaluate how vowel categories are organized within the overall vowel space of Dholuo.

The remainder of the paper is structured as follows. Section 2 describes the methodology used in the acoustic analysis, including the speaker sample, data collection procedures, and statistical analysis. Section 3 presents the results, focusing on the distribution of ATR vowel pairs and gender-related patterns in vowel space organization. Section 4 discusses the implications of these findings for the phonetic realization of ATR distinctions in Dholuo, followed by concluding remarks in Section 5.

2. Methodology

The data analyzed in this study were obtained from eight native speakers of Dholuo, consisting of four male and four female participants, with speakers equally distributed across the two major dialect areas. All participants were adult native speakers of Dholuo who acquired the language at home and used it as their primary means of communication during early childhood. Their formative years of schooling were also conducted in Dholuo, after which they were introduced to English and Kiswahili in formal education making them multilingual speakers.

Speech data were elicited through a controlled reading task designed to obtain tokens of the nine vowels of Dholuo, including both [\pm ATR] categories. Participants read a short carrier passage in Dholuo titled *Sigand Otiemo* (“The Story of Otiemo”), constructed to ensure a natural distribution of the vowel inventory while maintaining relatively comparable phonological environments. The passage consisted of a single paragraph and took approximately 90 seconds to read at a natural speaking rate. The passage contained 27 target vowel tokens embedded in lexical items, with each of the nine vowels represented multiple times. Target vowels occurred in both monosyllabic and disyllabic words, typically in CVC and CVCV syllable structures, where the vowel appeared between voiceless plosives. This phonological environment was selected because voiceless plosives exert minimal coarticulatory influence on adjacent vowels, thereby allowing clearer identification of the vowel’s steady-state portion for reliable F1 and F2 measurements. Each participant read the passage three times, resulting in repeated tokens of each vowel across productions.

Recordings were conducted in quiet indoor environments using a Zoom H5 digital recorder and stored as WAV audio files. The recordings were subsequently transferred to a computer for segmentation and acoustic analysis in Praat (Boersma & Weenink 2023). Segmentation was carried out at the segmental level. Vowel boundaries were identified through inspection of both the waveform and spectrogram: vowel onset was marked at the point where periodic voicing and a clear formant structure became visible, while vowel offset was marked at the point where periodicity and formant structure ceased. This procedure ensured that measurements were taken from stable portions of the vowel, minimizing the influence of adjacent consonantal transitions.

The initial dataset included recordings from all participants across three repetitions of the passage. During data screening, recordings from one speaker were excluded due to speech disfluencies that affected segmental stability and the identification of vowel steady-state portions, making reliable formant extraction difficult. In addition, acoustic outliers were identified following formant extraction. Both vertical and horizontal outliers were detected; however, only vertical outliers associated with F2 values were removed. Horizontal outliers associated with F1 values

were largely retained, as they were only slightly above threshold and did not introduce substantial variation in the dataset. Following these exclusion procedures, a total of 840 vowel tokens were retained for acoustic analysis.

Figure 2 illustrates a spectrographic representation of the vowel /a/ extracted from the word /bat/ ('arm'), showing the formant structure used in the acoustic analysis.

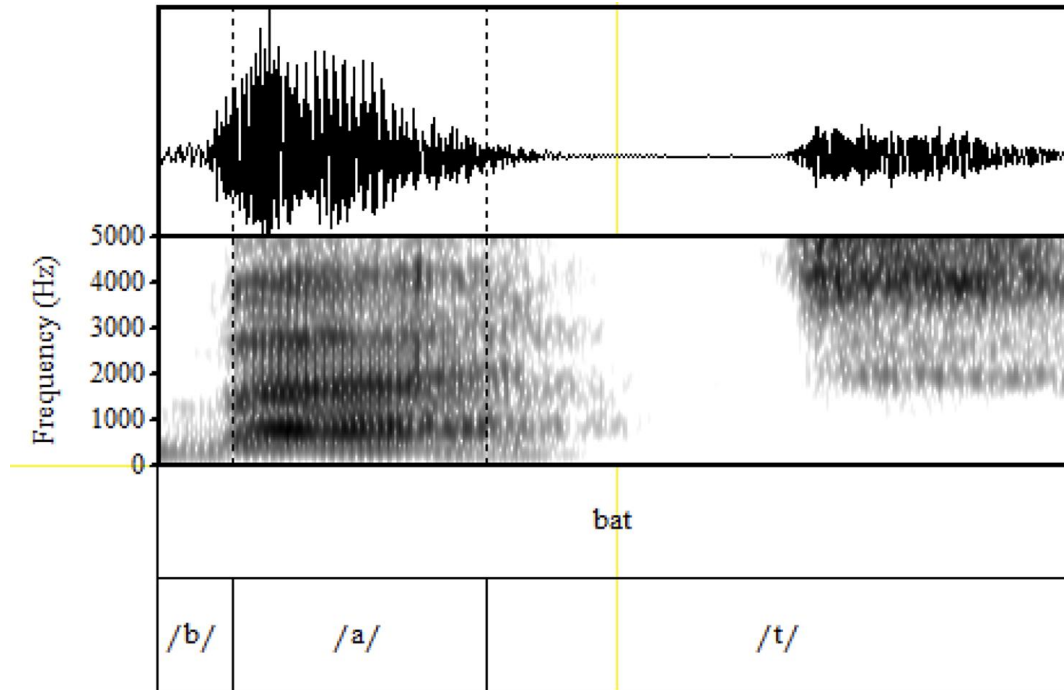


Figure 2. Spectrographic representation of the vowel /a/ extracted from the word /bat/

For each vowel token, the first and second formant frequencies (F1 and F2) were measured at the temporal midpoint of the vowel. Midpoint measurements were used to minimize the influence of formant transitions from adjacent consonants and to obtain a stable representation of vowel quality. The temporal midpoint is illustrated in Figure 2 by the vertical yellow line, which marks the point at which formant values were extracted. The vowel /a/ is used in Figure 2 for illustrative purposes because the figure is intended to demonstrate the segmentation and formant extraction procedure rather than to represent ATR contrasts. In Praat, vowel segments are identified based on their acoustic properties, such as periodicity and formant structure, which are common to all vowels regardless of their ATR specification. The choice of /a/ therefore provides a clear and representative example of vowel segmentation and measurement without implying any specific ATR-related pattern.

The analysis focuses on both F1 and F2 because these formants capture complementary acoustic dimensions of vowel articulation. F1 reflects vowel height and is closely associated with the acoustic realization of ATR distinctions, while F2 reflects the front-back dimension of vowel articulation. Although ATR contrasts are primarily realized through differences in F1, F2 is included to allow examination of how vowel categories are organized within the acoustic vowel space and to assess the degree of separation between vowel pairs across speakers.

Since formant frequencies vary across speakers due to physiological differences such as vocal tract length, the formant values were normalized prior to analysis. The normalization was carried out using the Lobanov (1971) z-score method, which standardizes formant values within each speaker's vowel system by adjusting them relative to the speaker's mean and standard deviation.

This procedure reduces inter-speaker variability attributable to anatomical differences while preserving the relative relationships among vowel categories within each speaker's system (Adank 2003; Watt & Fabricius 2002). The normalized values were subsequently used to construct vowel plots and examine patterns in the acoustic distribution of vowel categories.

The vowel-space plots were constructed by representing each vowel token as a point in a two-dimensional acoustic space defined by F1 (vertical axis) and F2 (horizontal axis). In this representation, F1 and F2 are plotted simultaneously, such that the position of each vowel reflects the combined contribution of both dimensions. As a result, the visual distance between vowel categories in the plot reflects their separation across both F1 and F2, rather than either dimension in isolation. This means that vowel pairs that differ primarily in F1 but show similar F2 values may appear more closely clustered in the two-dimensional space, while pairs that differ across both dimensions may appear more widely separated.

2.1 Statistical analysis

To evaluate whether the observed differences in vowel realization are statistically reliable, analyses of variance (ANOVA) were conducted on the normalized F1 values using R. Given that F1 serves as the primary acoustic correlate of the [\pm ATR] contrast, all statistical tests focused on variation in F1 across vowel categories. First, one-way ANOVAs were carried out separately for male and female speakers to assess whether vowel categories differ significantly within each speaker group. For the male data, the analysis revealed a significant effect of vowel on F1, $F(8, 395) = 72.96, p < .001$, indicating clear differentiation across the vowel inventory. A comparable analysis of the female data also showed a significant effect of vowel, $F(8, 427) = 13.21, p < .001$, confirming that vowel categories are systematically distinguished in both speaker groups. To further examine the role of speaker gender in shaping vowel realization, a two-way ANOVA was conducted with vowel and gender as fixed factors. The analysis revealed significant main effects of vowel, $F(8, 822) = 55.04, p < .001$, and gender, $F(1, 822) = 19.83, p < .001$, as well as a significant interaction between vowel and gender, $F(8, 822) = 5.05, p < .001$. This model allows for the evaluation of both overall differences between male and female speakers and variation in how individual vowel categories are realized across speaker groups.

Having established that differences in F1 values across vowels and speaker groups are statistically significant, the following section presents the acoustic results in detail. The analysis focuses on the distribution of F1 values and the organization of the vowel space, with particular attention to the realization of the [\pm ATR] contrast and its variation across speaker groups.

3. Results

This section presents the acoustic results based on normalized formant measurements. The analysis focuses primarily on F1 values to examine patterns associated with [\pm ATR] contrasts and on F1–F2 distributions to assess the organization of the vowel space. The results are presented in two stages: first, overall F1 patterns across the vowel inventory then, the distribution of vowel categories in the acoustic vowel space.

3.1 Mean F1 Values

This section presents data from the F1 values for both male and female speakers.

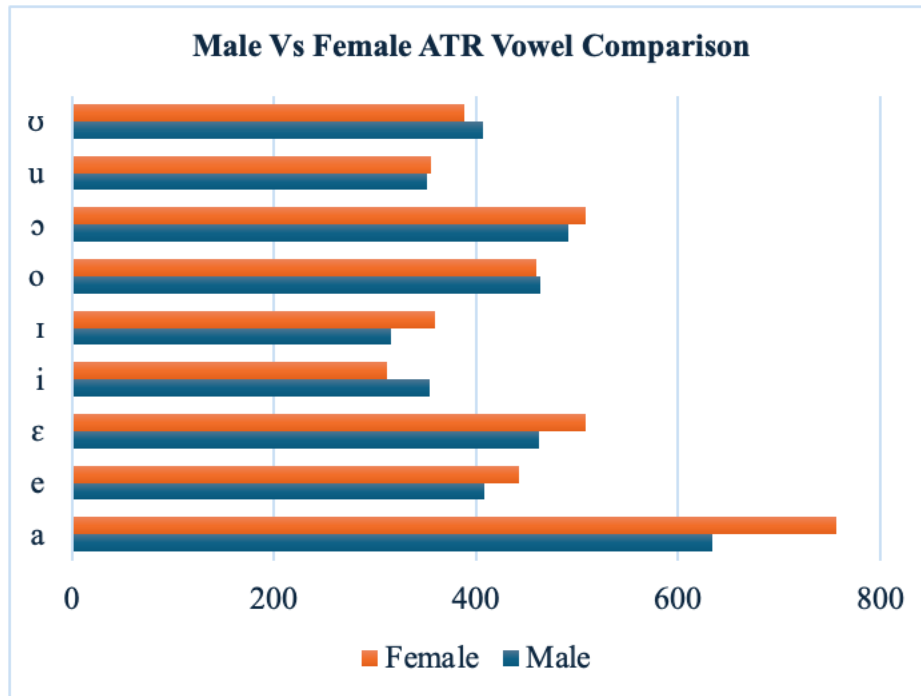


Figure 3. Mean F1 values for the nine Dholuo vowels produced by male and female speakers

Figure 3 presents mean F1 values for the nine Dholuo vowels produced by male and female speakers. The overall distribution reflects the expected height relationships within the vowel inventory: the low vowel /a/ exhibits the highest F1 values for both speaker groups, while the high vowels /i/ and /u/ occupy the lowest F1 range. Mid vowels are located between these extremes, producing a gradient distribution consistent with the articulatory and acoustic relationship between vowel height and F1 (Ladefoged & Johnson 2015).

Within this overall height-based organization, ATR vowel pairs display a systematic relationship in their F1 values. Across most pairs, vowels categorized as [−ATR] exhibit higher mean F1 values than their [+ATR] counterparts. This pattern is clearly observed in the mid and back vowel pairs /e−ε/, /o−ɔ/, and /u−ʊ/, where the separation between the two categories is visibly maintained in both speaker groups.

The high front vowel pair /i−ɪ/ shows a different pattern. In this case, the difference in mean F1 values between the two vowels is minimal, with the categories appearing closely aligned in the acoustic space. This reduced separation indicates that the ATR contrast for this pair is less clearly reflected in F1 values compared to other vowel pairs. Similar patterns have been reported in ATR systems where high vowels occupy a relatively compressed region of the vowel space, resulting in smaller measurable differences between categories (Hyman 2003; Casali 2008).

When male and female productions are considered together, the relative ordering of [+ATR] and [−ATR] vowels remain largely consistent across the vowel inventory. However, differences between speaker groups are not uniform. Female speakers exhibit higher mean F1 values than male speakers for several vowels, including the low vowel /a/, the mid vowels /e/ and /ε/, and the vowels /ɪ/, /ɔ/, and /u/. In contrast, a smaller set of vowels shows the opposite tendency, with male speakers displaying slightly higher F1 values for /i/, /o/, and /ʊ/.

Examining the ATR pairs more closely within each speaker group reveals both shared patterns and localized differences. In the female data, all four ATR vowel pairs (/i−ɪ/, /e−ε/, /o−ɔ/, /u−ʊ/) follow the expected directional pattern, with [+ATR] vowels consistently exhibiting lower F1

values than their [-ATR] counterparts. The magnitude of this difference varies across pairs, with the mid-vowel pair /e-ɛ/ showing one of the largest separations, while the high vowel pairs /i-ɪ/ and /u-ʊ/ display comparatively smaller differences.

In the male data, a similar directional pattern is observed for three of the four ATR pairs (/e-ɛ/, /o-ɔ/, and /u-ʊ/), where [+ATR] vowels exhibit lower mean F1 values than [-ATR] vowels. However, the high front pair /i-ɪ/ shows a different configuration: the [-ATR] vowel /ɪ/ appears with a slightly lower mean F1 value than the [+ATR] vowel /i/. This reversal contrasts with the pattern observed in the female data and indicates a localized irregularity in the realization of this vowel pair among male speakers.

Collectively, these patterns indicate that while the general relationship between ATR categories and F1 is maintained across the vowel inventory, the strength and consistency of this relationship vary across vowel pairs and across speaker groups. In particular, the mid-vowel region shows clearer separation between ATR categories, while the high vowel region, especially the /i-ɪ/ pair, exhibits reduced differentiation and greater variability.

3.2 Vowel space organization

This section presents the vowel plots on acoustic vowel space for female, male and combine plots for both speakers.

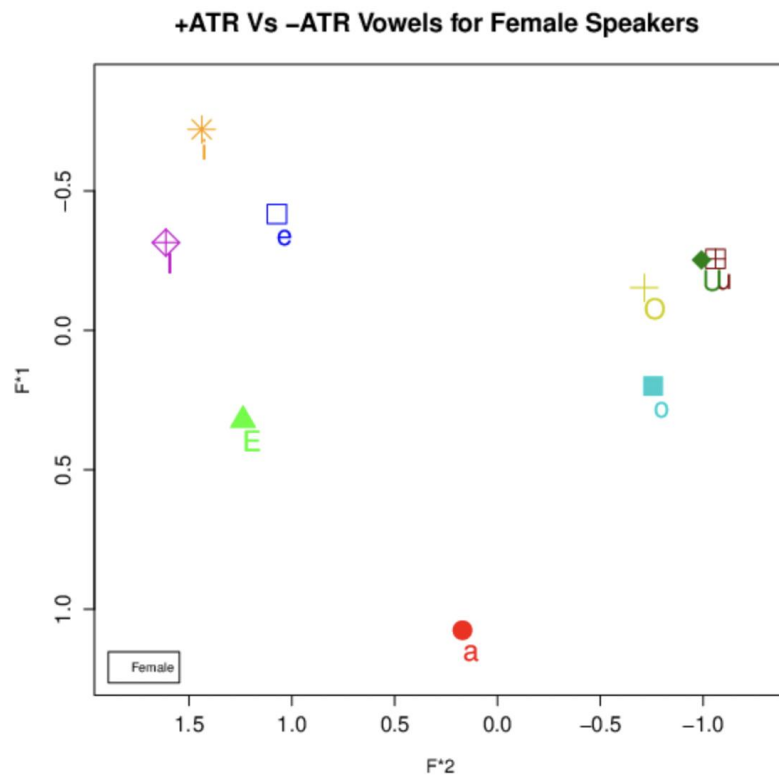


Figure 4. Female vowel space

Figure 4 presents female vowel space showing the distribution of the nine Dholuo vowels in normalized F1-F2 acoustic space. The vertical axis represents F1 (vowel height), with lower values (higher vowels) plotted toward the bottom of the figure, and higher values (lower vowels) toward the top. The horizontal axis represents F2 (front-back dimension), with higher values indicating fronter vowels. Capital letters (I, E, O, U) represent [-ATR] vowels (/ɪ, ɛ, ɔ, ʊ/), while lowercase

letters represent their [+ATR] counterparts. In this representation, vowel height is reflected along the F1 dimension, with higher vowels appearing toward the lower part of the plot and lower vowels toward the upper part. The overall configuration follows the expected pattern, with high vowels occupying the lower region, the low vowel /a/ appearing in the upper region, and front and back vowels distributed along the F2 dimension. Across all four ATR pairs (/i-ɪ/, /e-ɛ/, /o-ɔ/, /u-ʊ/), the [+ATR] vowels appear higher in the vowel space (lower F1 values) than their [-ATR] counterparts. In addition to this vertical separation, the plot shows differences in the spatial distribution of the vowel pairs. The mid front pair /e-ɛ/ (e-E) occupies clearly distinct regions of the space, with visible separation between the two categories. In contrast, the high back pair /u-ʊ/ (u-U) appears more closely clustered, with reduced overall distance between the two vowels in the two-dimensional space. The high front pair /i-ɪ/ also shows limited separation, with the two vowels occupying adjacent positions in the upper front region. The vowel-space representation therefore highlights differences in the degree of separation and overlap between vowel categories across the inventory, with some pairs occupying clearly distinct regions and others showing more compact configurations.

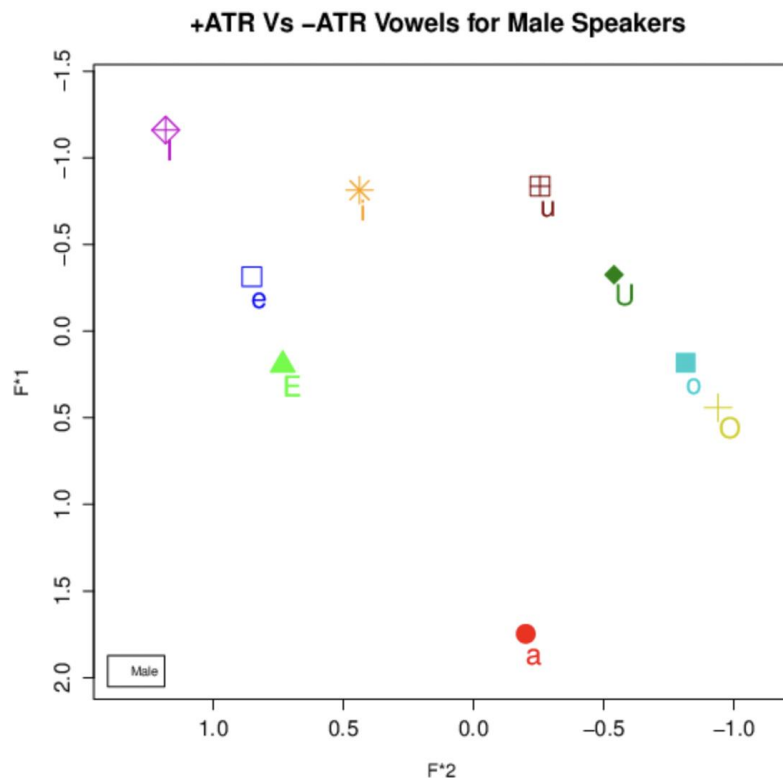


Figure 5. Male vowel space

Figure 5 displays male vowel space showing the distribution of the nine Dholuo vowels in normalized F1–F2 acoustic space. In this representation, vowel height is reflected along the F1 dimension, with higher vowels appearing toward the lower part of the plot and lower vowels toward the upper part. The overall configuration follows the expected pattern, with high vowels occupying the lower region, the low vowel /a/ appearing in the upper region, and front and back vowels distributed along the F2 dimension. Across most ATR pairs (/e-ɛ/, /o-ɔ/, /u-ʊ/), the [+ATR] vowels appear higher in the vowel space (lower F1 values) than their [-ATR] counterparts. The mid front pair /e-ɛ/ occupies relatively adjacent regions of the space, with a limited distance between the two vowels in both F1

and F2. The high back pair /u–ʊ/ occupies distinct but closely positioned regions, with visible separation between the two vowels in the F1–F2 space. The high front pair /i–ɪ/ shows a different configuration, with /ɪ/ appearing higher in the vowel space (lower F1) than /i/, resulting in a reversed vertical ordering for this pair. The vowel /a/ occupies the upper region of the space and appears slightly shifted toward the back along the F2 dimension, reflecting a position away from the central axis of the plot. In general, the male vowel space shows variation in the spacing and positioning of vowel categories across the inventory, with some pairs occupying clearly distinct regions, others appearing more closely clustered, and the high front pair displaying a non-canonical ordering.

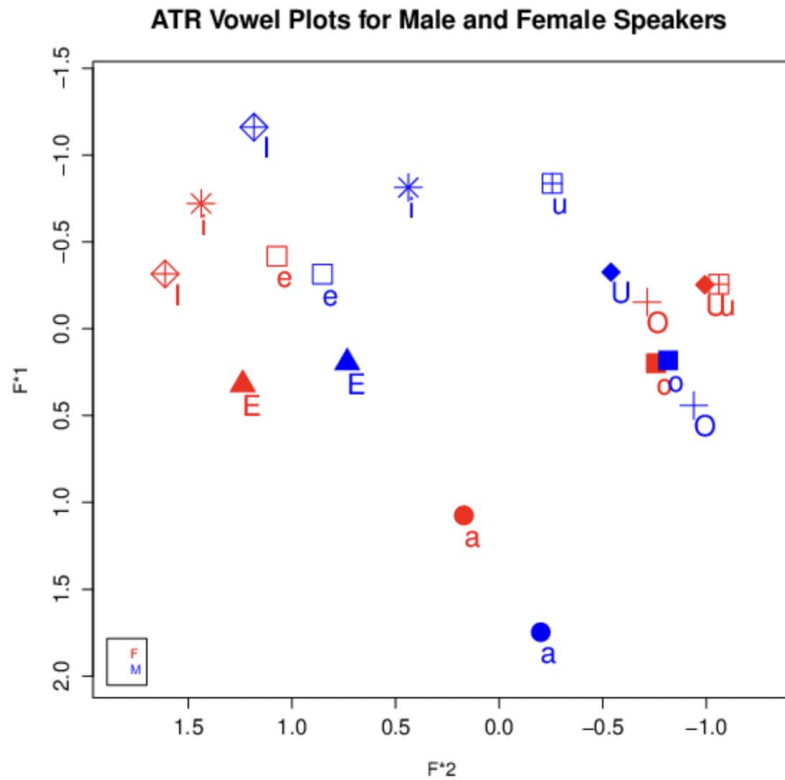


Figure 6. Combined vowel space for male and female speakers

Figure 6 presents the distribution of male and female vowel categories within a single normalized F1–F2 acoustic space. Having examined the male and female vowel spaces separately, this plot allows the two systems to be considered within a single normalized acoustic space. The combined representation makes it possible to observe the relative positioning and overlap of vowel categories across speaker groups. In several regions of the space, male and female realizations of corresponding vowels (e.g., /e, ɛ/ and /o, ɔ/) occupy overlapping areas, while other vowels show slight shifts in position across the two groups. The two-dimensional representation also makes visible patterns that are less apparent from F1 values alone. For instance, the high back pair /u–ʊ/, which shows a measurable difference in F1, appears more closely clustered in the F1–F2 space due to their similar F2 values. In contrast, the high front pair /i–ɪ/ in the male data shows a reversal in vertical ordering, with /ɪ/ appearing higher in the vowel space than /i/, a pattern that becomes more clearly observable when the vowels are viewed in the full acoustic space. Overall, the combined vowel space highlights both the overlap and the variation in the spatial organization of vowel

categories across speakers, showing that while the general structure of the vowel system is maintained, differences in positioning and spacing are present across the acoustic space.

4. Discussion

The results of this study provide a detailed account of how the $[\pm\text{ATR}]$ contrast is phonetically realized in Dholuo and allow for a more nuanced understanding of the relationship between phonological contrast and acoustic implementation. Consistent with previous analyses of ATR systems (Casali 2003, 2008; Archangeli & Pulleyblank 1994), the findings show that the contrast is primarily encoded through differences in F1, with $[\text{+ATR}]$ vowels generally exhibiting lower F1 values than their $[\text{-ATR}]$ counterparts. This pattern confirms that tongue-root advancement in Dholuo is acoustically reflected along the vowel-height dimension, aligning the language with broader cross-linguistic tendencies in ATR-based vowel systems.

At the same time, the results demonstrate that the strength of this contrast varies systematically across the vowel inventory. The mid-vowel pairs, particularly $/e-\varepsilon/$ and $/o-\text{o}/$, display clear and consistent separation in both the F1 measurements and the vowel-space representation, indicating a robust acoustic distinction. In contrast, the high-vowel pairs $/i-\text{i}/$ and $/u-\text{u}/$ show reduced separation, with smaller differences in F1 and more compact configurations in the vowel space. This pattern supports phonetic accounts which argue that high vowels occupy a relatively constrained region of the acoustic space, limiting the extent to which contrasts can be realized through F1 differences alone (Hyman 2003; Casali 2008). The Dholuo data therefore reinforce the view that ATR contrasts are not expressed uniformly across vowel pairs but are shaped by the phonetic constraints associated with vowel height and vowel-space organization.

A particularly noteworthy result concerns the behavior of the high front pair $/i-\text{i}/$. While the female data show only minimal separation between the two vowels, the male data exhibit a reversal of the expected ordering, with $/\text{i}/$ appearing higher in the vowel space than $/i/$. This non-canonical configuration indicates that the realization of this contrast is less stable in the high front region than elsewhere in the system. Rather than suggesting a change in the underlying phonological contrast, this pattern is more plausibly understood as a consequence of the limited acoustic space available for high front vowels, where small articulatory differences may not consistently translate into distinct acoustic values. Similar variability in high-vowel regions has been observed in other ATR systems (Casali 2008; Hyman 2003), but the present findings provide direct acoustic evidence of such variation within Dholuo.

The vowel-space analysis further refines the interpretation of these patterns by showing that the realization of vowel contrasts cannot be fully captured through F1 values alone. While F1 establishes the vertical organization of the vowel system and the primary encoding of the ATR contrast, the two-dimensional F1–F2 representation reveals differences in the degree of separation, overlap, and dispersion between vowel categories. For example, the $/u-\text{u}/$ pair, which shows a measurable difference in F1, appears relatively compact in the vowel space due to the similarity of the two vowels along the F2 dimension. In contrast, the $/e-\varepsilon/$ pair occupies clearly distinct regions in the acoustic space, reflecting differences across both F1 and F2. These patterns demonstrate that the perceptual and acoustic distinctiveness of vowel contrasts depends on the interaction of multiple dimensions rather than on a single formant alone.

The comparison between male and female speakers highlights an additional layer of variation in the realization of the vowel system. Although both groups maintain the same overall ATR-based structure, the female data show greater dispersion and clearer separation between several vowel categories, while the male data exhibit more compact distributions and localized irregularities, particularly in the high front region. In addition, differences are evident in the positioning of the low

vowel /a/, which appears more centrally located in the female vowel space but is shifted toward the back in the male data, as reflected in lower F2 values. This indicates that variation across speaker groups is not limited to the realization of ATR contrasts but also affects the spatial positioning of individual vowels within the acoustic system. Such patterns are consistent with sociophonetic findings that vowel realization may differ across speaker groups both in terms of dispersion and in the relative positioning of vowel categories (Labov 2006; Jacewicz, Fox & Salmons 2009).

More broadly, the findings contribute to ongoing discussions about the relationship between phonological contrast and phonetic realization in ATR vowel systems. The Dholuo data show that a phonologically stable contrast may be implemented with varying degrees of acoustic distinctiveness across vowel pairs and across speakers. This supports the view that phonological categories should not be equated with uniform acoustic patterns but rather understood as flexible targets whose realization is shaped by the phonetic constraints of the vowel space and by speaker-specific factors.

Finally, the study has important implications for research on Dholuo and related Western Nilotic languages. While previous descriptions have established the presence of a nine-vowel ATR system, the present analysis provides detailed acoustic evidence of how this system is structured in actual speech. In particular, the findings highlight both areas of stability, such as the consistent realization of mid-vowel contrasts, and areas of variability, such as the high-vowel region and the positioning of /a/. These results suggest that future research on Dholuo should adopt a more fine-grained approach to vowel analysis, focusing on vowel-specific patterns rather than treating ATR contrasts as uniformly realized across the inventory. More broadly, the study contributes to the comparative study of ATR systems by providing empirical data from Dholuo that both confirm established typological patterns and reveal areas of complexity that warrant further investigation.

5. Conclusion

This paper examined the acoustic realization of the [\pm ATR] contrast in Dholuo using normalized formant measurements from male and female speakers. The results show that the ATR distinction is consistently reflected in the acoustic structure of the vowel system, primarily through systematic differences in F1 values between [+ATR] and [-ATR] vowels. At the same time, the analysis demonstrates that the strength of this acoustic distinction varies across the vowel inventory. Mid vowels display clear and stable separation, while high vowels show reduced differentiation and more compact configurations in the acoustic space. The comparison between male and female speakers further indicates that vowel-space organization may differ across speaker groups in terms of dispersion and positioning, while preserving the overall structure of the system. By providing detailed acoustic evidence from Dholuo, this study contributes to the phonetic documentation of ATR vowel systems in African languages and offers a more fine-grained account of how phonological contrasts are realized across vowel categories and speakers. The findings highlight that ATR contrasts are systematically maintained, but not uniformly realized, reflecting the interaction between phonological structure and the phonetic constraints of the vowel space.

Acknowledgements

The author gratefully acknowledges Kenyatta University for providing the academic environment in which this research was developed. I am particularly grateful to my supervisors, Joshua Itumo and Gatitu Kiguru, for their patience, guidance, and support throughout the research process.

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