An Acoustic Analysis of the Relationship between Vowel Height and Tone in Dholuo

Jane Akinyi Ngala Oduor

University of Nairobi

oduor_jane@uonbi.ac.ke

Abstract

This study investigated the relationship between vowel height and tone in Dholuo, a Nilotic language spoken in western Kenya. Dholuo has two main dialects; this study focused on the Kisumu–South Nyanza variety. Previous research, notably Hombert (1978), suggests that vowel height may influence tonal realization, with high vowels tending to raise pitch. However, the extent and direction of this effect are known to vary across languages. To determine whether vowel height affects tonal realization in Dholuo, lexical items bearing high and low tones were selected for analysis. These items contained the low vowel /a/ and the high vowels /u/, /ʊ/, /i/, and /ɪ/. Four native speakers of Dholuo (two male and two female) participated in the study. Their productions were recorded directly into a computer using Speech Analyzer software and an external microphone. The recorded data were phonetically transcribed, after which Speech Analyzer was used to extract fundamental frequency (F0) values for the vowels, measured in Hertz (Hz). For each vowel–tone combination, the sum and mean F0 values were calculated. The results showed that differences in the pitch levels of both high and low tones across high and low vowels were not statistically significant. Nevertheless, the findings support the widely observed cross-linguistic tendency for high vowels to be associated with higher pitch, thus confirming a universal predisposition, even though this effect does not appear to be phonologically robust in Dholuo.

Keywords: vowel height, tonal realization, Dholuo, frequency (F0), high and low tones, acoustic analysis

Introduction

Dholuo belongs to the Nilotic group of languages. Its speakers are found mainly in Kenya, particularly along the eastern shores of Lake Victoria, although some speakers reside in major urban centres across the country. A smaller population of Dholuo speakers is also found in Tanzania, along the shores of Lake Victoria. According to Oduol (1990), the Dholuo spoken in Kenya has two major dialects: Kisumu–South Nyanza (KSN) and Boro–Ukwala (BU). The segmental inventories of the two dialects do not differ; rather, the differences are manifested in tonal usage and in a limited number of lexical items. The present study focuses on the Kisumu–South Nyanza (KSN) variety.

Previous phonetic research has demonstrated a relationship between vowel height and fundamental frequency. As noted by Hombert (1978): "Several studies have shown that American English vowels have an intrinsic fundamental frequency related to their height: High vowels (low F1) have a higher fundamental frequency than low vowels … "(p. 97). Hombert (1978) cites earlier studies by Black (1949), House and Fairbanks (1953), and Lehiste and Peterson (1961) in support of this claim. He further observes that research on other languages, including Danish, French, Korean, and Serbo-Croatian, has similarly revealed a correlation between vowel height and fundamental frequency (F0). These findings suggest that, in some languages, vowel height plays a role in influencing tonal realization, such that high vowels may raise the pitch level of the tones with which they co-occur, regardless of whether the tone is phonologically high or low.

The present study seeks to determine whether this phonetic relationship holds in Dholuo. Specifically, it investigates whether high vowels in Dholuo raise the pitch level of the tones they bear. Accordingly, the study addresses the following research question: What is the phonetic relationship between vowel height and tone level in Dholuo? This question may be restated as follows: Do high vowels in Dholuo have a measurable effect on tone level?

Based on cross-linguistic evidence, the study assumes that high vowels, in contrast to low vowels, have the potential to raise the pitch level of the tone with which they are articulated. In other words, it is hypothesized that high vowels in Dholuo may increase the level of the tone they bear.

Dholuo has a nine-vowel system consisting of /a/, /e/, /ɛ/, /i/, /ɪ/, /u/, /ʊ/, /o/, and /ɔ/ (Oduor, 2002). These vowels are phonemically short but may be lengthened in certain phonological environments (see Okombo, 1982; Ngala, 1994, p. 139; Oduor, 2002, pp. 65–66). The high vowels examined in this study are /u/, /ʊ/, /i/, and /ɪ/. The effect of these vowels on tonal realization is investigated in environments in which they occur both as short vowels and as long vowels. Their influence on tone is compared with that of /a/, a low vowel, in comparable phonological environments.

Brief Literature on Tone

The literature review in this section is brief because it touches on only a few studies that have focused on the relationship between vowel height and tone. The tones found in Dholuo are also mentioned.

Tone and Vowel Height

Hombert (1978) observes that a number of scholars "have suggested that different vowels may give rise to contrasting tones" (p. 96). He further notes that several theoretical accounts have been proposed to explain "why high vowels have a higher intrinsic fundamental frequency than low vowels" (Hombert, 1978, pp. 97–98). One such account is the *tongue-pull theory*. According to Hombert (1978), drawing on the work of Ladefoged (1964) and Lehiste (1970), this theory is based on the assumption that, "…when the tongue is in a high position for the realization of high vowels, it exerts an extra tension transmitted to the larynx via the hyoid bone." (p. 98).

Hombert (1978) further reports, citing Ohala (1972), that this vertical pull increases the tension of the vocal cords, resulting in a higher pitch for high vowels. In support of this

view, Ohala and Eukel (1976) demonstrated that an increased pull of the tongue on the laryngeal structures enhances fundamental frequency (F0) differences between low and high vowels. However, subsequent studies reviewed by Hombert (1978) indicate that the transmission of this pull does not occur via the hyoid bone, thereby calling into question the precise physiological mechanism proposed by the tongue-pull theory. Although understanding the articulatory mechanisms involved in vowel production is important, the primary concern of the present study is not the physiological explanation itself, but rather whether high vowels in Dholuo actually raise the level of the tone with which they are articulated.

In contrast to the findings discussed above, Hombert (1978) notes that in some languages, such as Ngizim and Bade, low vowels have been observed to give rise to high tones. This suggests that the direction of the relationship between vowel height and tone is not uniform across languages. The present study therefore seeks to establish the direction of this relationship in Dholuo, specifically whether high vowels give rise to higher tone levels or not.

Further evidence challenging the universality of intrinsic fundamental frequency (IF0) effects in tone languages is provided by Connell (2002), who investigated IF0 in Ibibio, Mambila, Kunama, and Dschang. Connell (2002) conducted his study under the assumption that IF0 exists in tone languages, but his findings were interpreted as indicating that “IF0 may be constrained in tone languages, even to the point where it can be said not to occur” (p. 123). He reports that:

All of the languages investigated in this study showed a smaller than average degree of IF0 and one, Mambila, apparently showed no IF0. However, the size of tone inventory alone apparently cannot account for the reduction or disappearance of IF0. Rather, the nature of the tone system, and specifically the degree of F0 modulation used in producing tonal

contrasts (to some extent a consequence of inventory size), appears to be the primary factor. (Connell, 2002, p. 123)

Given that Dholuo is a tone language with both lexical and grammatical functions, it is therefore possible that it may exhibit little or no intrinsic fundamental frequency effect. This study seeks to empirically determine whether IF0 operates in Dholuo and, if so, the extent to which vowel height influences tonal realization.

Types of Tone in Dholuo

According to Oduor (2002), Dholuo has a tonal system comprising primarily low (L), high (H), downstepped high (ꜜH), low rising (LH), and high falling (HL) tones (see Oduor, 2002, for a detailed discussion). In the present study, attention is restricted to the two level tones, namely low and high. These two tones are considered sufficient for the purposes of this research, as they allow for a focused examination of the phonetic relationship between vowel height and tone level without the additional complexity introduced by contour tones.

Procedure, Instruments, and Limitations

This section outlines the procedures followed in the study, including data selection, methodological approach, research instruments, and issues related to data quality and limitations. To carry out the study systematically, words containing low and high tones were identified for analysis. Some of these words formed minimal pairs differing in the vowels involved (see Graphs 1, 2, and 3 below). The selected lexical items contained the low vowel /a/ and the high vowels /u/, /ʊ/, /i/, and /ɪ/, as specified in the introduction, including their lengthened variants in appropriate phonological environments. In some cases, the words included affixes, predominantly suffixes, which were retained as part of the natural morphological structure of the language.

The analysis excluded words containing mid vowels, even though such vowels occurred in some of the data, since the comparison between high and low vowels was

considered sufficient for the purposes of the study. Similarly, contour tones and the downstepped high tone were excluded, as the focus of the investigation was restricted to the relationship between vowel height and level tones, namely high and low tones.

Four native speakers of Dholuo participated in the study: two male speakers and two female speakers. The male speakers were labelled Male 1 (M1) and Male 2 (M2), while the female speakers were labelled Female 1 (F1) and Female 2 (F2). Although Ladefoged (1999, p. 140) recommends a minimum of six speakers (three male and three female) for phonetic research, and suggests that samples of up to twelve or twenty speakers per sex may be ideal (Ladefoged, 2003, p. 14), the number of participants in this study was considered adequate. This is because a sufficient number of vowel tokens was elicited from each speaker to allow for meaningful analysis. Ladefoged (2003, p. 14) further notes that, in some cases, researchers have had to be "satisfied with four or five speakers," particularly when working with endangered or under-documented languages. Even in studies of non-endangered languages, relatively small speaker samples are common. For instance, Connell (2002), in a study comparable to the present one, used four speakers for each of the African languages investigated—Ibibio, Mambila, Kunama, and Dschang. Connell (2002, p. 107) justifies this practice by observing that more than half of the studies reviewed by Whalen and Levitt (1995), which have contributed substantially to our understanding of the relationship between vowel height and tone, employed five or fewer speakers.

Each speaker was recorded directly into a computer using Speech Analyzer software and an external microphone. The recording settings were 44,100 Hz sampling rate and 16-bit mono resolution. These settings ensured that the acoustic quality of the recordings was appropriate for detailed phonetic analysis. Although the words were recorded in isolation rather than within a carrier frame, each item was repeated three times to ensure consistency and to minimize variation in vowel and tonal realization. The recordings were conducted in a

relatively small room equipped with curtains, and the available seating was made of heavy fabric. These conditions helped to reduce sound reverberation and external noise, thereby enhancing recording quality. In addition, the settings used in Speech Analyzer were suitable for the analysis of both male and female voices.

The recorded data were listened to repeatedly as necessary to confirm the tonal categories of the selected words. The data were then transcribed phonetically. Speech Analyzer was used to extract and record the pitch levels of vowels bearing high tones and low tones, as illustrated in Graphs 1, 2, and 3. The vowels were analyzed in environments where they occurred both as long and as short vowels (see Appendices 1 and 2). In Graphs 1, 2, and 3, the upper panels display the waveform (left) and spectrogram (right), while the lower panels show intensity (left) and pitch (right). Pitch measurements were taken at points judged to be the most stable and representative of the tonal target. Decisions regarding pitch measurement points and segment boundaries were informed by inspection of the waveform and intensity contours, while the spectrogram was particularly useful in identifying clear segment boundaries. Some of the data were analyzed using an earlier version of Speech Analyzer, while the remainder were analyzed using a more recent version of the software.

Tone measurements were recorded in Hertz (Hz). For each speaker, the high tone on long vowels [iː, ɪː, uː, ʊː, aː] was measured and recorded. For each vowel, nine pitch readings were obtained. The lexical items used for this purpose are listed in Appendix 1. In cases where words were repeated, pitch measurements were taken from vowels occurring in different syllables. For example, the word [θíríŋíːɲí] contains three short [ɪ] vowels, and the tone level on each vowel was measured separately. The sum and mean pitch values for the high tone on each vowel were calculated and recorded. The same procedure was applied to the high tone on short vowels [i, ɪ, u, ʊ, a], the low tone on long vowels [iː, ɪː, uː, ʊː, aː], and the low tone on short vowels [i, ɪ, u, ʊ, a]. For each vowel category, nine measurements were

obtained per speaker. The mean values across speakers were then calculated and presented in Graphs 16, 17, and 18.

The study had several limitations that should be acknowledged. First, it was not possible to rely exclusively on minimal pairs, and a number of words that did not form minimal pairs were therefore included in the data set. Second, it was not feasible to record all speakers in a single recording session; some speakers were recorded across multiple sessions, and different speakers were recorded on different days. Third, the words were recorded in isolation rather than within a carrier frame. However, the words were read continuously and without unnecessary pauses to maintain a natural speaking style, and speakers were instructed not to raise their voices beyond their normal conversational level. Despite these limitations, careful effort was made to ensure that data quality was not compromised. On the basis of the procedures described above, the data were considered sufficiently reliable to support the interpretation of the findings presented in the results and discussion section that follows.

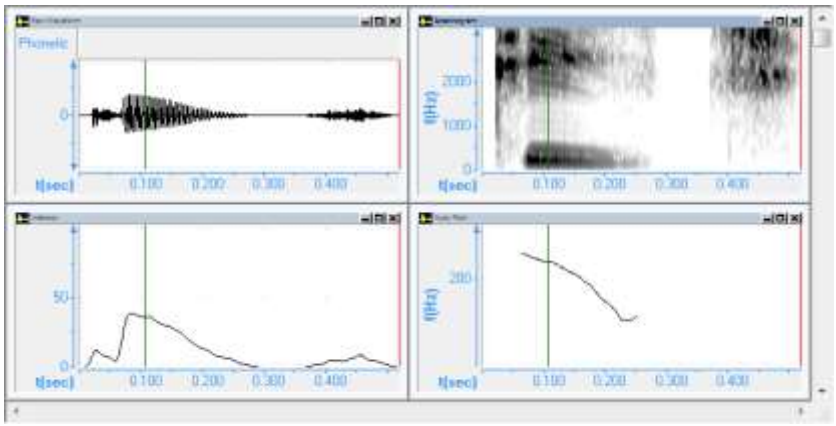
Results and Discussion

Graphs 1, 2, and 3 illustrate that the words presented to the speakers were identical in all respects except for one segment, namely the vowel. Specifically, the vowels represented in Graphs 1, 2, and 3 are [iː], [uː], and [aː], respectively. For each graph, the corresponding tone measurements, expressed in Hertz (Hz), are provided below the figures. Importantly, all three graphs are derived from productions by the same speaker, thereby controlling for inter-speaker variation.

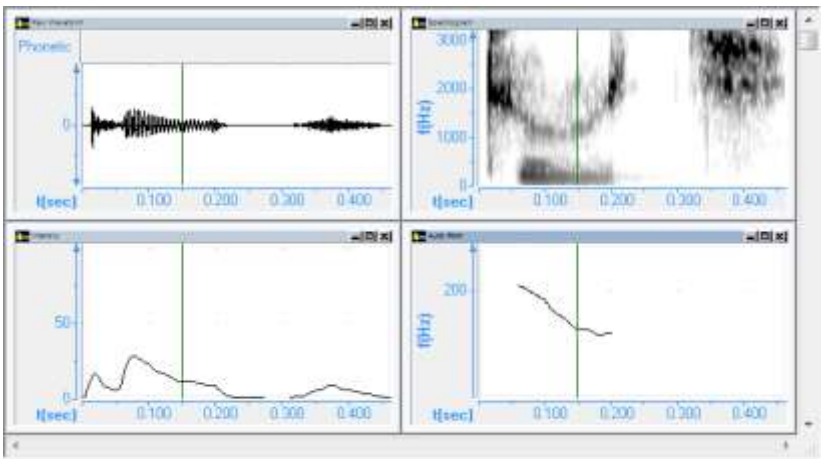
For this particular speaker, the vowel [iː] exhibited the highest pitch level, followed by [aː], and then [uː]. This pattern indicates that, in some cases, a low vowel such as [aː] may bear a higher tone than a high vowel such as [uː]. Such an observation runs counter to the hypothesis that high vowels systematically raise the pitch level of the tones with which they co-occur. On the basis of this hypothesis, high vowels would be expected to bear higher high

tones than low vowels. However, in the case of the low vowel in the word [tà:c] and the high vowel in [tù:c], the opposite pattern is observed, with the low vowel displaying a higher pitch level.

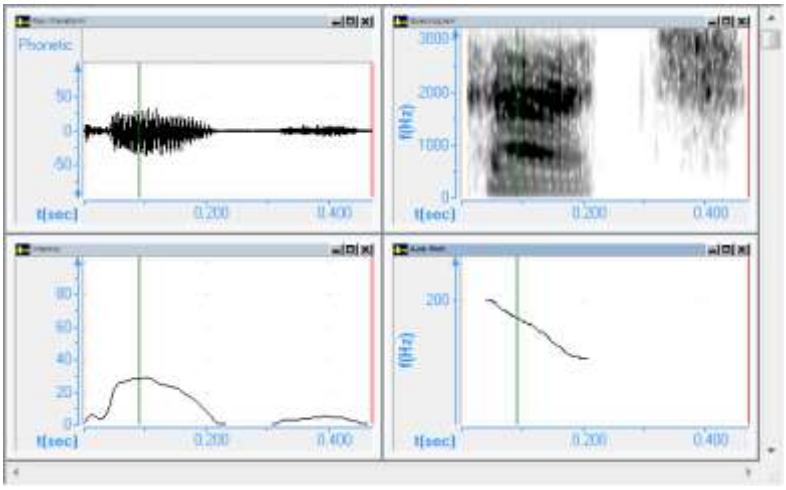
By contrast, the high vowel [i:] conforms to the expectations of the hypothesis when compared with the low vowel [a:], as it bears a higher tone. These mixed results suggest that the relationship between vowel height and tone level in Dholuo is not uniform across vowels or lexical items. Rather than showing a consistent effect whereby all high vowels raise tone level relative to low vowels, the data reveal variability both within and across vowel categories. The three graphs illustrating these patterns are presented below.



Graph 1: [tù:c] 220Hz



Graph 2: [tù:c 162.8Hz



Graph 3: [tà:c] 185.3Hz

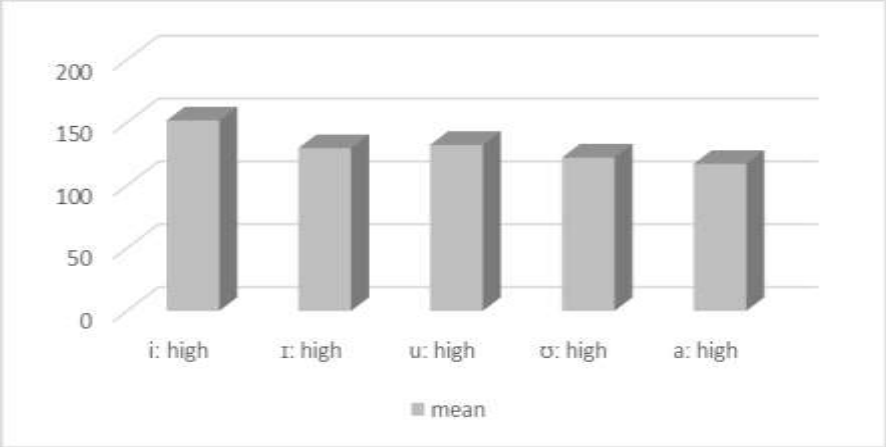
All the words in Table 1 below bear a low tone, and the tone of the penultimate vowel was the target of measurement. The three words do not exhibit a consistent pattern across all speakers. For Male 1 (M1), the highest pitch was recorded on the vowel [i:], followed by [a:], and finally [u:]. In contrast, for Male 2 (M2) and Female 1 (F1), the highest pitch occurred on [u:], followed by [i:], and then [a:]. For Female 2 (F2), the highest pitch was on [i:], followed by [u:], and finally [a:]. These observations indicate that the pitch level of a vowel is not automatically higher when the vowel is high rather than low. Overall, vowel height does not appear to exert a strong or consistent influence on tone level in Dholuo. Furthermore, for M1 and F2, the pitch recordings of the three vowels are relatively close, providing additional evidence that vowel height does not substantially affect tonal realization in this language.

Table 1: Low Tone Recordings on the Penultimate Vowel for Each of the Four Speakers

Dholuo (IPA)	English gloss	M1	M2	F1	F2
pì:kɔ̀	To insert	140	144.5	227	202.3
pù:kò	To pour	129.7	168.1	252	191.9
pà:kɔ̀	To praise	130.9	126.4	197.5	180.4

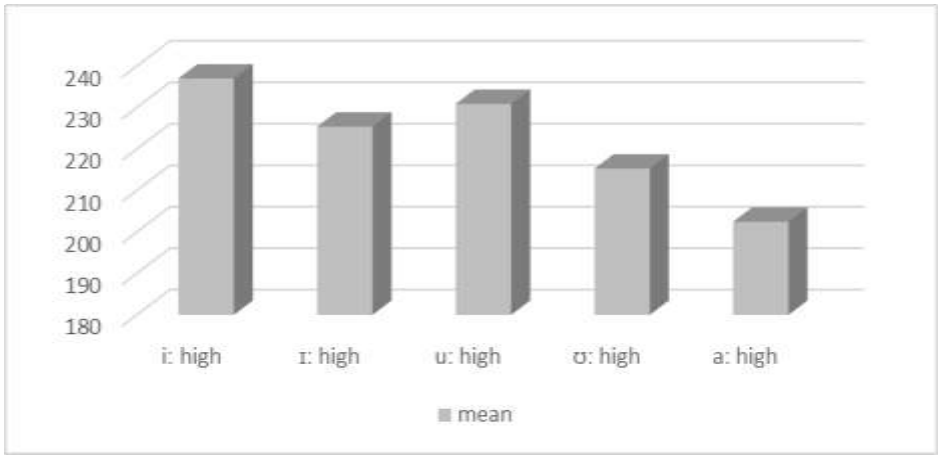
In Graph 4, the mean values of the high tone on the five long vowels for the male participants are presented. The data show that, on average, the front vowels exhibit higher pitch levels than the back vowels, as evidenced by [i:] having a higher mean than [u:] and [ɪ:]

having a higher mean than [ʊː]. However, as will be demonstrated in subsequent analyses, this pattern is not consistently observed across all speakers or vowel contexts. Importantly, within this set of vowels, all high vowels exhibit a higher mean pitch for the high tone than the low vowel [aː], supporting, to some extent, the expectation that high vowels tend to bear higher tones than low vowels in Dholuo.



Graph 4: The Mean of the High Tone on the Long Vowels for Male Participants

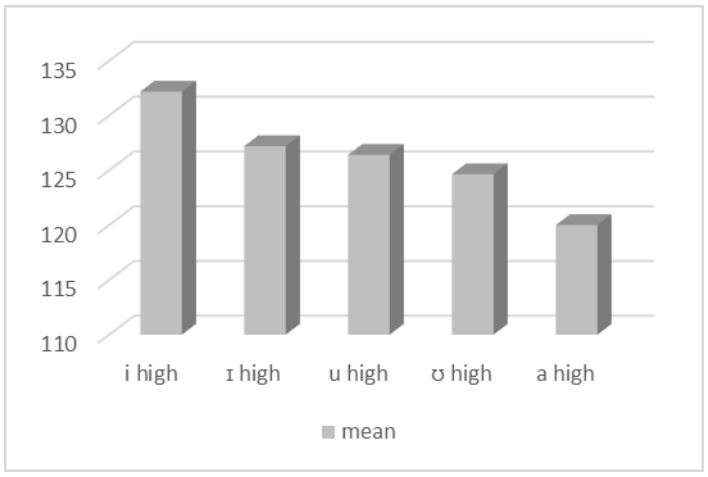
For the female participants, as expected, the overall pitch levels were higher than those of the male participants. However, the pattern of high tone realization across vowels, shown in Graph 5, mirrored that of the male speakers. The mean high tone values, in descending order, were [iː] (194.31 Hz), [uː] (181.53 Hz), [ɪː] (177.48 Hz), [ʊː] (168.66 Hz), and [aː] (159.76 Hz). Consistent with the male data, the front vowels exhibited higher pitch levels than the back vowels, and all high vowels had higher pitch values than the low vowel [aː]. These results indicate a similar relationship between vowel height and high tone across male and female speakers, although absolute pitch values are elevated for the female participants, reflecting expected physiological differences in fundamental frequency.



Graph 5: The Mean of the High Tone on the long Vowels for Female Participants

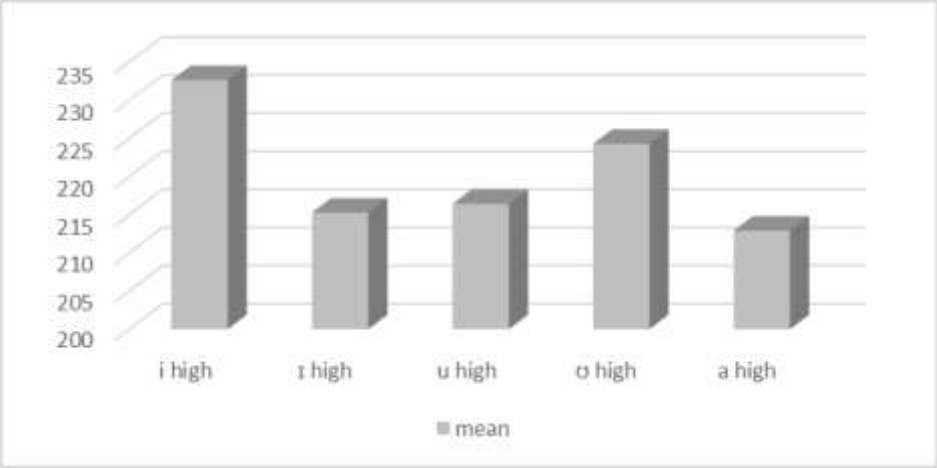
As expected, the pitch recordings of the male participants were generally lower than those of the female participants. For Male 1 (M1), the mean high tone values for the long vowels, in descending order, were [iː] (156.08 Hz), [uː] (132.07 Hz), [ɪː] (126.67 Hz), [aː] (122.24 Hz), and [ʊː] (122.02 Hz). Interestingly, the low vowel [aː], which would be expected to have the lowest high tone if intrinsic fundamental frequency (IF0) were fully operative, exhibited a slightly higher pitch than [ʊː]. For Male 2 (M2), the order was slightly different: [iː] (147.17 Hz), [ɪː] (132.49 Hz), [uː] (132.29 Hz), [ʊː] (122.10 Hz), and [aː] (111.87 Hz). The female participants' recordings aligned more closely with expectations based on vowel height. For Female 1 (F1), the mean high tones were [iː] (239.67 Hz), [uː] (237.33 Hz), [ɪː] (239.38 Hz), [ʊː] (228.89 Hz), and [aː] (206.90 Hz), while for Female 2 (F2), they were [iː] (234.33 Hz), [uː] (224.41 Hz), [ɪː] (211.38 Hz), [ʊː] (201.63 Hz), and [aː] (198.01 Hz) (see Appendix 2A). The order observed for F1 and F2 corresponds more closely with the expected vowel-height hierarchy in Dholuo, which, according to Ochieng (Forthcoming, pp. 9–10), is [i], [u], [ɪ], [ʊ], [e], [o], [ɛ], [ɔ], and [a], with [i] being the highest and [a] the lowest vowel. Connell (2002) supports this expectation, noting that "no difference in IF0 should be expected between front and back vowels, even when this is extended to include more than just high vowels. Duration was also shown not to influence the intrinsic F0 of vowels in the absence of corresponding differences in vowel quality" (p. 123).

By contrast, the mean high tone patterns for M1 and M2 did not consistently follow the expected height hierarchy observed in the female recordings. In Graph 6, the mean high tone values for the five short vowels for male participants are presented. The order, from highest to lowest pitch, was [i], [ɪ], [u], [ʊ], and [a]. This analysis shows that front vowels again exhibit higher pitch levels than back vowels, and that all high vowels maintain higher high tones than the low vowel [a]. These results suggest that while the expected relationship between vowel height and pitch is more clearly realized in female speakers, a similar trend is present in male speakers, albeit with greater variability.



Graph 6: The Mean of the High Tone on the Short Vowels for Male Participants

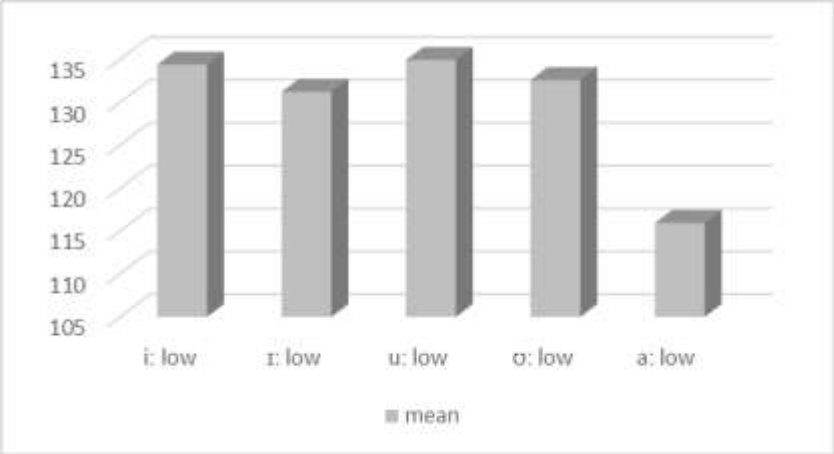
Graph 7 presents the mean high tone values for the five short vowels produced by the female participants. The order of vowels, from highest to lowest pitch, is [i], [ʊ], [u], [ɪ], and [a]. This pattern differs slightly from the trends observed in Graphs 4, 5, and 6. Notably, the high back vowels ([ʊ] and [u]) exhibit higher mean pitch values than one of the high front vowels ([ɪ]). Despite this variation, all high vowels still demonstrate higher pitch levels than the low vowel [a]. These findings suggest that while vowel height generally correlates with higher tone, there may be additional phonetic or speaker-specific factors influencing the realization of high tones in Dholuo, particularly among short vowels.



Graph 7: The Mean of the High Tone on the Short Vowels for Female Participants

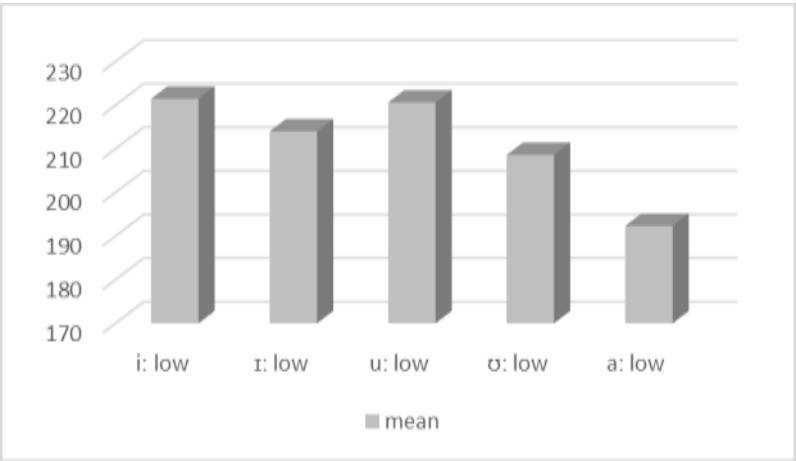
The mean high tone values for the short vowels produced by M1, M2, F1, and F2, from highest to lowest, were as follows: M1-[i] (136.59 Hz), [ɪ] (133.41 Hz), [u] (127.81 Hz), [a] (124.03 Hz), [ʊ] (122.13 Hz); M2-[i] (127.79 Hz), [ʊ] (127.16 Hz), [u] (125.02 Hz), [ɪ] (122.01 Hz), [a] (115.99 Hz); F1-[i] (239.33 Hz), [ʊ] (228.54 Hz), [ɪ] (223.31 Hz), [u] (216.88 Hz), [a] (216.37 Hz); and F2-[i] (226.00 Hz), [ʊ] (220.09 Hz), [u] (216.01 Hz), [a] (209.51 Hz), [ɪ] (207.28 Hz) (see Appendix 2B). A close examination of these values reveals that there is no consistent ordering of the vowels across speakers for the high tone on short vowels, indicating substantial inter-speaker variation in tonal realization.

Graph 8 presents the mean low tone values on the five long vowels for male participants. The ordering, from highest to lowest low tone, was [uː], [iː], [ʊː], [ɪː], and [aː]. Notably, all high vowels exhibited higher low tone levels than the low vowel [aː], suggesting that the relative vowel height continues to influence tone even at the low level, although the effect may be more variable than for the high tone.



Graph 8: The Mean of the Low Tone on the Long Vowels for Male Participants

In Graph 9, the mean low tone values on the five long vowels for female participants are presented. The ordering of vowels, from highest to lowest low tone, is [iː], [uː], [ɪː], [ʊː], and [aː]. This pattern is similar to the results observed in Graphs 4 and 5, in that all high vowels exhibit higher pitch levels than the low vowel [aː]. These findings reinforce the general trend across speakers and tonal levels, indicating that vowel height in Dholuo tends to correspond with relatively higher tone realization, even for low tones, although some variability between individual speakers is evident.

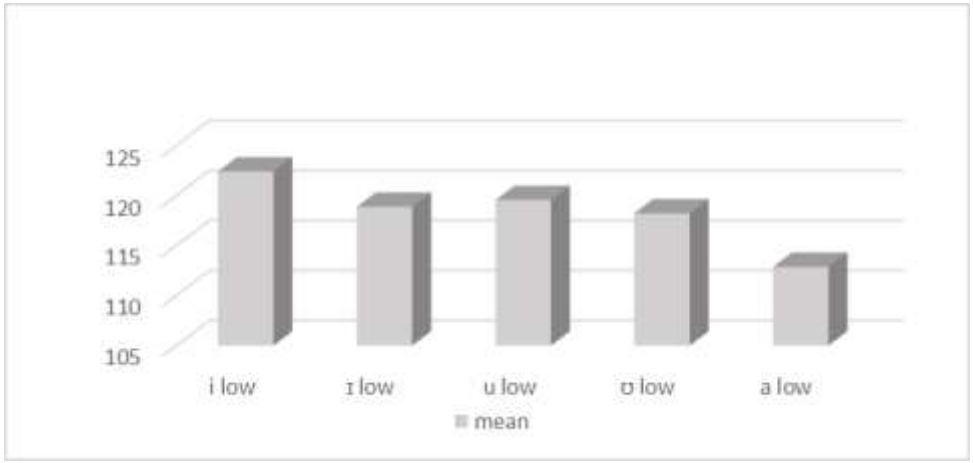


Graph 9: The Mean of the Low Tone on the Long Vowels for Female Participants

The mean low tone values for the long vowels produced by M1, M2, F1, and F2, from highest to lowest, were as follows: M1-[ʊː] (138.33 Hz), [iː] (136.98 Hz), [ɪː] (136.62 Hz), [uː]

(133.28 Hz), and [aː] (118.57 Hz); M2-[uː] (136.62 Hz), [iː] (131.82 Hz), [ʊː] (126.88 Hz), [ɪː] (125.84 Hz), and [aː] (113.33 Hz); F1-[uː] (251.89 Hz), [ɪː] (230.11 Hz), [iː] (230.00 Hz), [ʊː] (226.34 Hz), and [aː] (198.08 Hz); and F2-[iː] (212.93 Hz), [ɪː] (197.83 Hz), [ʊː] (190.84 Hz), [uː] (189.36 Hz), and [aː] (186.59 Hz) (see Appendix 2C). A close examination of these figures reveals that there is no fully consistent pattern in the ordering of vowels across speakers. Nevertheless, a notable trend is that the low vowel [aː] consistently exhibits the lowest mean pitch value for each speaker.

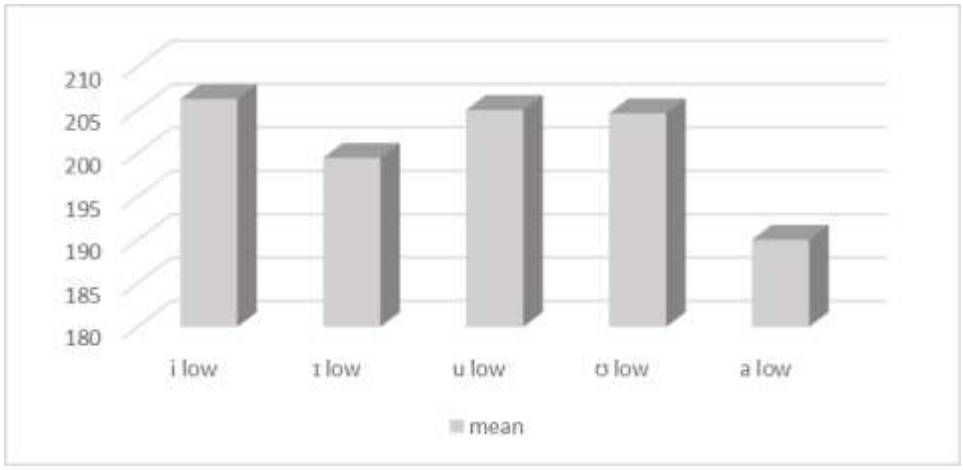
In Graph 10, the mean low tone values for the five short vowels produced by male participants are presented. The ordering, from highest to lowest pitch, is consistent with the patterns observed in Graphs 4, 5, and 9: [i], [u], [ɪ], [ʊ], and [a]. As in the long vowels, all high vowels display higher low tone values than the low vowel [a], further supporting the general observation that vowel height in Dholuo tends to correspond with relatively higher pitch levels, even for low tones, despite some variability among individual speakers.



Graph 10: The Mean of the Low Tone on the Short Vowels for Male Participants

Graph 11 presents the mean low tone values on the five long vowels for the female participants. The ordering of the vowels, from highest to lowest pitch, is [iː], [uː], [ʊː], [ɪː], and [aː]. Consistent with the patterns observed in all preceding graphs, the high vowels exhibit higher low tone values than the low vowel [aː]. These results reinforce the general

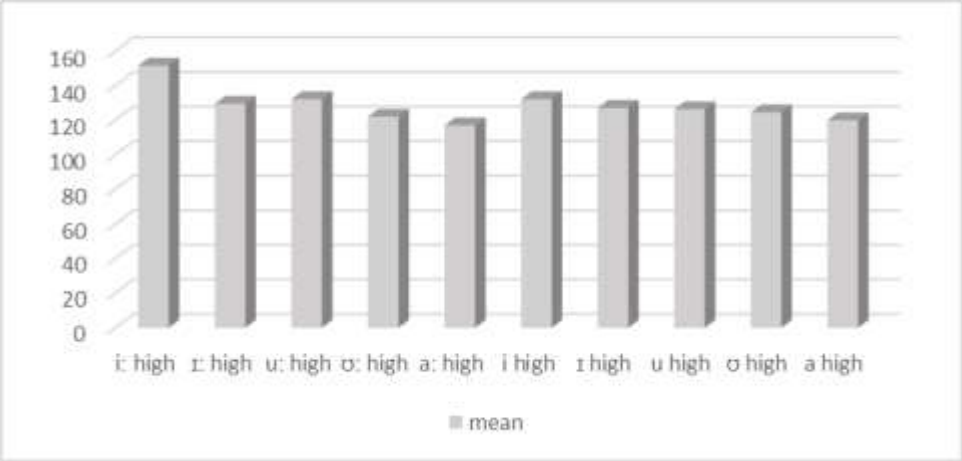
trend across speakers and vowel categories, indicating that vowel height in Dholuo is generally associated with relatively higher pitch levels, even at the low tone level.



Graph 11: The Mean of the Low Tone on the Short Vowels for Female Participants

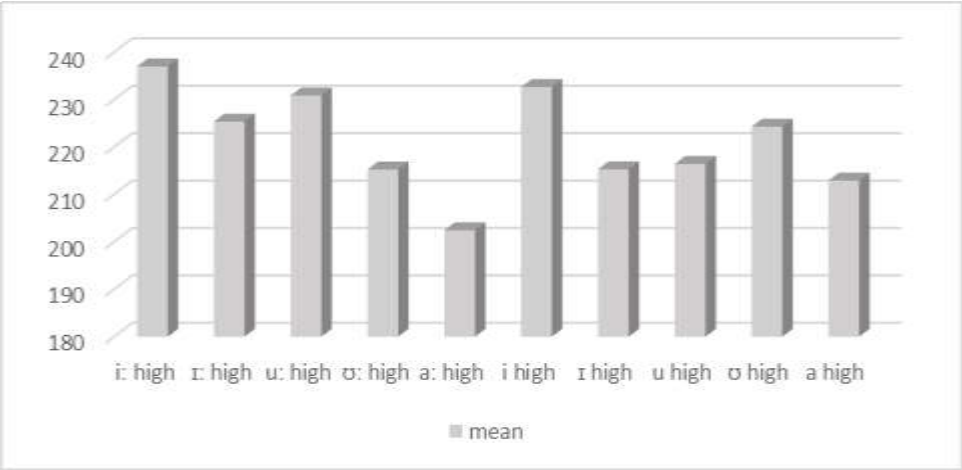
The mean low tone values for the short vowels produced by M1, M2, F1, and F2, from highest to lowest, were as follows: M1-[iː] (127.21 Hz), [ɪː] (122.66 Hz), [aː] (114.91 Hz), [uː] (113.37 Hz), [ʊː] (113.21 Hz); M2-[uː] (125.72 Hz), [ʊː] (123.22 Hz), [iː] (117.61 Hz), [ɪː] (115.09 Hz), [aː] (110.83 Hz); F1-[uː] (223.68 Hz), [ʊː] (214.39 Hz), [iː] (209.34 Hz), [ɪː] (201.46 Hz), [aː] (189.70 Hz); and F2-[iː] (203.21 Hz), [ɪː] (197.51 Hz), [ʊː] (194.89 Hz), [aː] (190.42 Hz), [uː] (186.36 Hz) (see Appendix 2D). M2 and F1 exhibited a similar ordering of vowels, whereas M1 and F2 differed in their patterns. This demonstrates that, while some trends are consistent across speakers, inter-speaker variability in low tone realization persists.

Graph 12 presents the mean high tone values for all vowels, both long and short, produced by male participants. The ordering, from highest to lowest high tone, is [iː], [i], [uː], [ɪː], [ɪ], [u], [ʊ], [ʊː], [a], and [aː]. Notably, all high vowels display higher high tone values than the low vowels [a] and [aː], reinforcing the general pattern observed throughout the dataset that vowel height in Dholuo is associated with relatively higher pitch levels for high tones.



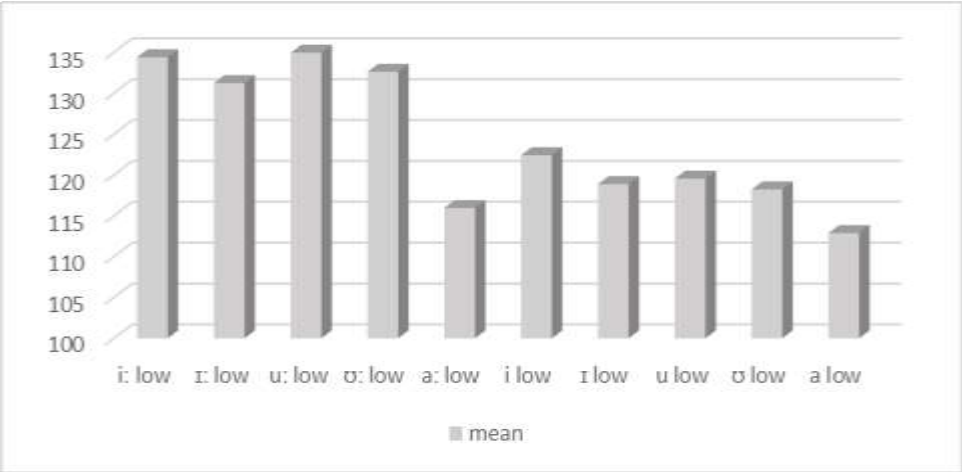
Graph 12: The Mean of the High Tone on the Long and Short Vowels for Male Participants

The mean of the high tone on the long and short vowels used in the study for female participants is presented in Graph 13. The order of the vowels starting with the vowel with the highest high tone is [iː], [i], [uː], [ɪː], [ʊ], [u], [ɪ], [ʊː], [a], and [aː]. Once again, all the high vowels have a higher high tone than the low vowels [a] or [aː].



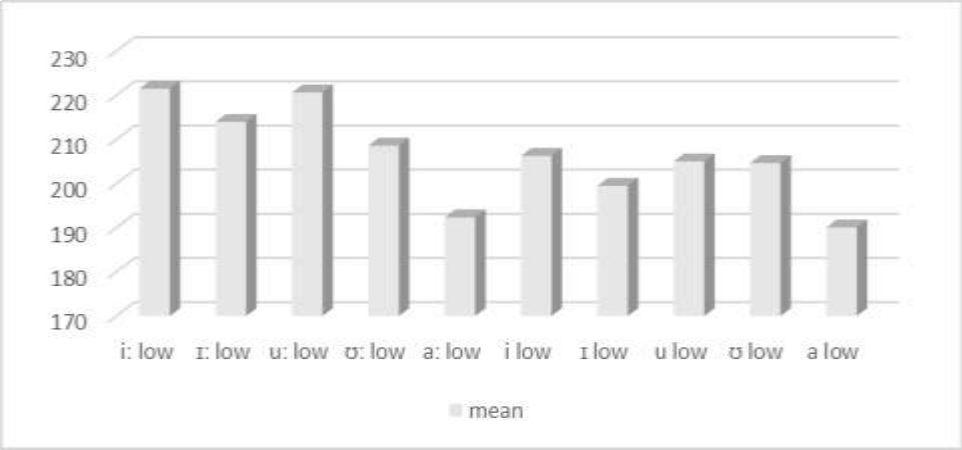
Graph 13: The Mean of the High Tone on Long and Short Vowels for Female Participants

The mean of the low tone on all the vowels used in the study for male participants is presented in Graph 14. The order of the vowels starting with the vowel with the highest low tone is [uː], [iː], [ʊː], [ɪː], [i], [u], [ɪ], [ʊ], [aː] and [a]. Just as in graphs 12 and 13, all the high vowels have a higher low tone than the low vowels [a] or [aː].



Graph 14: The Mean of the Low Tone on Long and Short Vowels for Male Participants

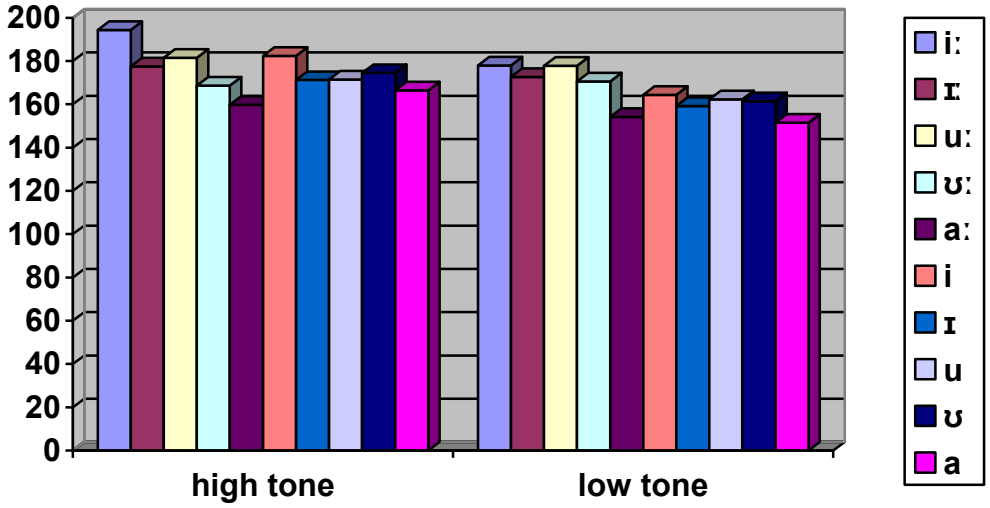
The mean of the low tone on the short and long vowels for female participants is presented in Graph 15. The order of the vowels starting with the vowel with the highest low tone is [iː], [uː], [ɪː], [ʊː], [i], [u], [ʊ], [ɪ], [a;] and [a]. Just as already recorded for graphs 12, 13, and 14, all the high vowels have a higher tone than the low vowels [aː] or [a].



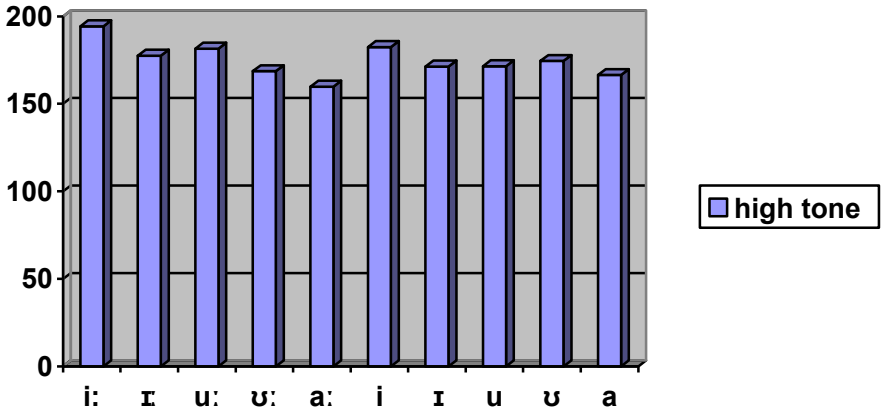
Graph 15: The Mean of the Low Tone on Long and Short Vowels for Female Participants

Graph 16 illustrates that the differences in pitch levels associated with high and low vowels, for both high and low tones, are not statistically significant. The graph is intended to demonstrate the general trend rather than highlight precise differences. It reflects the widely

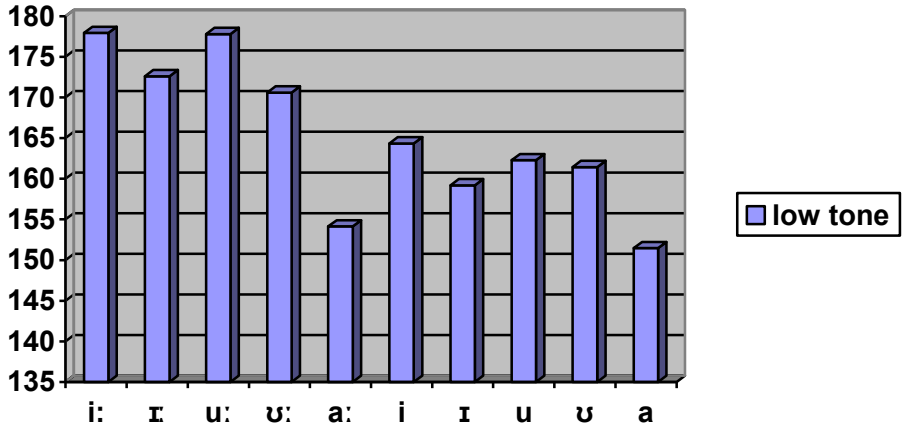
attested universal tendency for high vowels to co-occur with slightly higher pitch. Statistical analysis of the tones for each vowel, as shown in Graphs 16, 17, and 18, confirmed that high vowels exhibit marginally higher pitch values than the low vowel. Additionally, high tone recordings were generally higher than low tone recordings, which aligns with expected phonetic patterns. All pitch values are reported in Hertz. While Graph 16 presents the combined means of both high and low tones for each vowel, Graphs 17 and 18 provide a more detailed view, with Graph 17 displaying the mean high tone values for each vowel and Graph 18 showing the mean low tone values.



Graph 16: The Grand Mean of the High and Low Tones on Each Vowel Used in the Study



Graph 17: The Grand Mean of the High Tone on the Vowels Used in the Study



Graph 18: The Grand Mean of the Low Tone on the Vowels Used in the Study

The analyses indicate that the low vowels [aː] and [a] consistently exhibit the lowest fundamental frequency (F0) across all graphs presented in this section. The sole exception is observed in the mean high tone values for the long vowels of one male participant (M1), for whom the mean F0 values, from highest to lowest, were [iː] (156.08 Hz), [uː] (132.07 Hz), [ɪː] (126.67 Hz), [aː] (122.24 Hz), and [ʊː] (122.02 Hz). In this instance, the vowel with the lowest F0 was [ʊː], rather than the low vowel [aː]. This exception highlights the presence of individual variability in F0 realization, even within the general pattern of higher F0 for high vowels and lower F0 for low vowels.

Conclusion

This study was based on the premise that high vowels in Dholuo, unlike low vowels, have the potential to raise tone. The results, however, showed that for some speakers the low vowel [aː] could bear a higher tone than a high vowel such as [uː], contrary to our initial assumption that high vowels would elevate the pitch of the tone they bear. For example, in the words [tàːtʃ] (low vowel, low tone), [tùːtʃ] (high vowel, high tone), and [tìːtʃ] (high vowel, high tone), the expected pattern was not consistently observed across speakers. In particular, the low tone of the high vowel [iː] met expectations when compared with the low vowel [aː],

but the overall pattern across the three words showed no systematic increase in tone level associated with high vowels. For several participants, the pitch values of these vowels were very similar (see Appendices), further indicating that vowel height does not substantially influence tone level in Dholuo.

In general, the study concludes that there is no significant relationship between vowel height and tone level in Dholuo. High vowels produce only a slight elevation in the pitch of both low and high tones. Nevertheless, these findings align with the universally observed tendency for high vowels to slightly raise the tone level. Future research could extend this study to include the mid vowels of Dholuo, which were not examined in the present investigation, to determine whether similar patterns hold across the full vowel inventory.

References

Black, J. W. (1949). Natural frequency, duration and intensity of vowels in readings. *Journal of Speech and Hearing Disorders, 14*, 216–221.

Connell, B. (2002). Tone languages and the universality of intrinsic F0: Evidence from Africa. *Journal of Phonetics, 30*(1), 101–129. https://doi.org/10.1006/jpho.2001.0156

Hardcastle, W. J., & Laver, J. (Eds.). (1999). *The handbook of phonetic sciences*. Blackwell Publishers.

Hombert, J. M. (1978). Consonant types, vowel quality, and tone. In V. A. Fromkin (Ed.), *Tone: A linguistic survey* (pp. 77–111). Academic Press.

House, A. S., & Fairbanks, G. (1953). The influence of consonant environment upon the secondary acoustical characteristics of vowels. *Journal of the Acoustical Society of America, 25*, 105–113.

Ladefoged, P. (1964). *A phonetic study of West African languages*. Cambridge University Press.

Ladefoged, P. (1999). Instrumental techniques for linguistic phonetic fieldwork. In W. J. Hardcastle & J. Laver (Eds.), *The handbook of phonetic sciences* (pp. 137–166). Blackwell Publishers.

Ladefoged, P. (2003). *Phonetic data analysis*. Blackwell Publishing.

Lehiste, I. (1970). *Suprasegmentals*. MIT Press.

Lehiste, I., & Peterson, G. E. (1961). Some basic considerations in the analysis of intonation. *Journal of the Acoustical Society of America, 33*, 419–425.

Ngala, J. A. (1994). *A contrastive analysis of the English (RP) and Dholuo syllable structures* (Unpublished master's thesis). Moi University.

Ochieng, M. (forthcoming). Dialectal variation in Dholuo: An acoustic study of formants and vowel space configuration. *Journal of the Language Association of Eastern Africa*.

Oduol, J. H. A. (1990). *Dholuo dialects: Synchronic state and some historical inferences* (Unpublished doctoral dissertation). University of Nairobi.

Oduor, J. A. N. (2002). *A study of syllable weight and its effects on Dholuo phonology* (Unpublished doctoral dissertation). University of Nairobi.

Ohala, J. J. (1972). How is pitch lowered? *Journal of the Acoustical Society of America, 52*, 124.

Ohala, J. J., & Eukel, B. W. (1976). Explaining the intrinsic pitch of vowels. *Journal of the Acoustical Society of America, 60*, S44.

Okombo, D. O. (1982). *Dholuo morphophonemics in a generative framework*. Dietrich Reimer Verlag.

Whalen, D. H., & Levitt, A. G. (1995). The universality of intrinsic F0 of vowels. *Journal of Phonetics, 23*, 349–366.

APPENDICES

Appendix 1

Elicitation List

Informants: M1, M2, F1, and F2

[í:] high tone Dholuo IPA	English gloss	M1	M2	F1	F2
í:˯tá	My ear	162.1	156.1	237	238
í:˯tí	Your (singular) ear	174.9	158.4	252	244
í:tú	Your (plural) ears	152.2	150.8	248	230
rí:˯ŋgá	My meat	139.8	148.1	261	244
dí:k	Blunt	149.8	135.7	242	222
í:té	His/her ears	139.5	147.3	228	225
rí:ŋgé	His/her meat	166.4	137.8	246	230
kí:té	Stones	154.8	141.8	225	238
bí:m	Monkey	165.2	148.5	218	238
	Sum	**1404.7**	**1324.5**	**2157**	**2109**
	Mean	**156.0778**	**147.1667**	**239.66667**	**234.3333**

[ì:] low tone		M1	M2	F1	F2
wì:c	Head	119.1	135.6	233	213
tì:c	Work	134.9	146.4	239	220
pì:rò	To nurse or baby sit	144.8	121.4	230	209.6
cì:lò	Dirt	147.5	135.7	227	213
kì:tá	My character	122.4	133.9	229	203.8
kì:té	His/her character	147	117.6	229	220
kì:tí	Your (singular) character	144.1	134.3	225	210
kì:tú	Your (plural) character	132.6	135.9	232	213
rì:cò	Bad (plural)	140.4	125.6	226	214
	Sum	**1232.8**	**1186.4**	**2070**	**1916.4**
	Mean	**136.9778**	**131.8222**	**230**	**212.9333**

[í] high tone		M1	M2	F1	F2
cà:cí	Your (singular) tea	124.3	120.7	231	217
ò:dí	Your (singular) house	140.7	123.9	248	223
ò:rí	Your (singular)	139.6	120.9	252	231

	brother-in-law				
	Your (singular)				
kì:tí	character	148.2	142.3	250	227
lì:mí	Visit you	136.6	136.4	259	230
	Your (singular)				
wè:ndí	visitor	144.5	127.6	243	229
	Your (singular)				
dè:ndí	body	143.6	120.9	220	217
òrí:ndí	A low stool	131.2	112.3	225	233
kè:tí	Put	120.6	145.1	226	227
	Sum	**1229.3**	**1150.1**	**2154**	**2034**
	Mean	**136.5889**	**127.7889**	**239.33333**	**226**

[ì] low tone		M1	M2	F1	F2
ɲì:rì	Girls	110.1	94.2	189.1	168.5
wìckùòt	Shame	154.8	129.3	224	232
wìcbà:r	Headache	146	117.3	231	234
gìkmó:kó	Other things	146.3	128.6	217	214
kùdnì	Worm	105.3	100.9	173.6	160.9
rìknì	Hurry	106.6	102.5	162.1	185.7
ɟìkô:n	Kitchen	111.9	123.8	203.3	200.8
wìcwì:l	Forgetfulness	130.6	133.1	241	216
rìknì	Hurry	133.3	128.8	243	217
	Sum	**1144.9**	**1058.5**	**1884.1**	**1828.9**
	Mean	**127.2111**	**117.6111**	**209.34444**	**203.2111**

[í:] high tone		M1	M2	F1	F2
mábí:θ	Sharp one	144.9	133.5	208.4	186.4
àdí:tá	Basket	130.4	115.8	219	211
àhí:ɲá	Very much	147	128.6	227	214
líŋlí:ŋ	Secretly	128.5	128.4	215	192.8
mí:né	Mothers	111.6	121.8	258	204.2
ŋí:c	Wetness	118.3	152.1	264	211
lí̤:t	Sorrow	120.2	152.6	253	224
pí:ɲ	Down	118.3	130.3	258	229
tí:n	Small	120.8	129.3	252	230
	Sum	**1140**	**1192.4**	**2154.4**	**1902.4**
	Mean	**126.6667**	**132.4889**	**239.37778**	**211.3778**

[ì:] low tone		M1	M2	F1	F2
bì:jɔ̀	To squeeze out	128.9	118.8	230	200.1
rì:ŋgɔ̀	To run	133.6	119.9	223	192.6
pì:kɔ̀	To insert	140	144.5	227	202.3
	To squeeze or				
dì:jɔ̀	press	132.6	121.7	250	190.1
ì:ðɔ̀	To climb	138.3	131.5	216	198.2

cì:mɔ̀	To face	148.2	134.4	230	200.4
tì:ndɔ̀	Small ones/ to eat sparingly	134.8	131.6	240	197.6
gì:dɔ̀	To tickle	141.9	116	234	202.3
lì:mɔ̀	To visit	131.3	114.2	221	196.9
	Sum	**1229.6**	**1132.6**	**2071**	**1780.5**
	Mean	**136.6222**	**125.8444**	**230.11111**	**197.8333**

[í] high tone		M1	M2	F1	F2
ŋà:θí	Child	138.1	115.7	217	186.6
θíríṇí:ŋí	Stark/completely	141.9	129.8	240	222
θíríṇí:ŋí	Stark/completely	144.6	119.8	241	219
θíríṇí:ŋí	Stark/completely	118.2	113.3	210	180.1
mátíntí:n	Small proportions	158	137.1	241	223
mísɔ́:mbá	Bachelor	148.4	120.8	231	209.6
líŋlí:ŋ	Secretly	144.3	117.1	231	210
ɔ̀jɔ́:ndí	A kind of bird	98.1	116.9	204.9	207.2
rà:ŋí	Mirror	109.1	118.6	193.9	208
	Sum	**1200.7**	**1089.1**	**2009.8**	**1865.5**
	Mean	**133.4111**	**121.0111**	**223.31111**	**207.2778**

[ì] low tone		M1	M2	F1	F2
mìlìmì:lì	Sweet	132.4	121.4	232	206.1
mìlìmì:lì	Sweet	127.6	106.5	209	199.6
pìlɛ̀pì:lɛ̀	Every day	135.1	133.8	216	222
mìnɛ̀:mɛ̀	Jiggers	134.1	111.9	206.1	208
pìjɔ̀pì:jɔ̀	Quickly	128.3	119.5	226	219
ìckà:c	Stomachache	145.8	137.5	225	214
lɔ̀àŋnì	House fly	95.1	94.6	151.9	161.7
mbɔ̀àknì	Unsettled behaviour	94.1	95.2	158.3	156.3
ŋàdìrì:jɔ̀	Twice	111.4	115.4	188.8	190.9
	Sum	**1103.9**	**1035.8**	**1813.1**	**1777.6**
	Mean	**122.6556**	**115.0889**	**201.45556**	**197.5111**

[ú:] high tone		M1	M2	F1	F2
àgú:lú	Pot	139.9	123.9	219	236
àú:má	Name of a person	122.9	119.9	231	227
fú:ˈjɔ́	To fly	160.9	163.9	272	249
mátú:t	Deep one	158.6	115.6	220	195.7
bàrú:pé	Letters	117.3	121.5	217	213
ràú:m	Cover	115.6	120.7	236	219
ú:n	You (plural)	121.3	146.4	259	225

bú:rú	Dust/ ash	126.1	137.1	249	223
kú:lɔ́	Fetching water from a river,etc	126	141.6	233	232
	Sum	**1188.6**	**1190.6**	**2136**	**2019.7**
	Mean	**132.0667**	**132.2889**	**237.33333**	**224.4111**

[ù:] low tone		M1	M2	F1	F2
pù:rò	To dig	131.4	133.3	241	190.3
pù:kò	To pour	129.7	168.1	252	191.9
kù:dò	To gaggle	130.9	143.3	254	187
tù:ndò	To reach	131.6	132.3	245	193.9
tù:c	To get a hole (of dress)	139	126.1	264	162.8
tù:cò	To pierce	138.2	118.3	237	200.8
gù:dò	To gather	131.6	136.3	261	192.7
rù:cò	To rub	133.3	138.3	255	195.5
dù:k	Naked	133.8	133.6	258	192.6
	Sum	**1199.5**	**1229.6**	**2267**	**1707.5**
	Mean	**133.2778**	**136.6222**	**251.88889**	**189.3625**

[ú] high tone		M1	M2	F1	F2
àgú:lú	Pot	117.4	115.9	196.5	217
cà:cú	Your (plural) tea	120.7	132.9	214	217
í:tú	Your (plural) ears	128.6	130.6	214	209.5
ò:dú	Your (plural) house	130.6	124.9	222	223
ò:rú	Your (plural) brother-in-law	128.2	123.9	221	224
kì:tú	Your (plural) character	144	138.9	257	223
wè:ndú	Your (plural) visitor	128.1	134.4	212	214
kóáû:rú	Please ask for (reflexive)	122.2	110.6	200.4	205.6
nɛ́úû:rú	Please see (reflexive)	130.5	113.1	215	211
	Sum	**1150.3**	**1125.2**	**1951.9**	**1944.1**
	Mean	**127.8111**	**125.0222**	**216.87778**	**216.0111**

[ù] low tone		M1	M2	F1	F2
ŋɟù:gù	Gound nuts	125.3	129.3	173.1	157.8
kùlòré	To bend (reflexive)	116.7	128.5	228	187.9
mùkòré	To uproot	108.9	126.9	230	181.1

	(reflexive)				
pùkòré	To pour (reflexive)	109.3	126.9	221	197.4
rùcòré	To rub (reflexive)	111.7	123.4	237	188.8
tùcòré	To pierce (reflexive)	111.7	126.1	221	201.1
gùdòré	To gather (reflexive)	112	123.1	233	188.4
bùlòré**	To roast (reflexive)	109.1	125.4	234	188.5
rùdòré	To stir (reflexive)	115.6	121.9	236	186.2
	Sum	**1020.3**	**1131.5**	**2013.1**	**1677.2**
	Mean	**113.3667**	**125.7222**	**223.67778**	**186.3556**

[ó:] high tone		M1	M2	F1	F2
só:ná	Mosquito	143.5	133.9	217	211
mísó:mbá	Bachelor	142.3	120.7	217	189.1
ɔ̀mbó:ló	Vote	108.1	116.6	217	206.1
màɲó:rú	A woman who has just given birth	111.1	121.5	220	205.1
só:já	Smell	118.9	120.1	235	236
ɔ̀jó:ndí	A kind of bird	114.3	113.1	235	204.2
tór átó:rá	Just break	118.2	124.3	222	172.6
cón ácó;ná	Just force	122.3	119.3	233	174.6
fó:ló	A kind of fish	119.5	129.4	264	216
	Sum	**1098.2**	**1098.9**	**2060**	**1814.7**
	Mean	**122.0222**	**122.1**	**228.88889**	**201.6333**

[ò:] low tone		M1	M2	F1	F2
cò:nɔ̀	To force	137.8	121.5	235	191.7
mò:rɔ̀	To warm	126.3	129.7	238	195.1
cò:lɔ̀	To pay	147.6	130.9	238	193.1
ràpò:dɔ̀	Slim	136.9	111.4	166.1	175.2
lò:wɔ̀	To follow	142.8	130.7	227	190.9
bò:ndɛ̀	Gun	143.2	128.3	227	194.3
ɲò:lɔ̀	To swallow without chewing properly	149.9	127.8	224	190.9
rò:jɔ̀	To rush or do something hurriedly	131.6	127.4	241	196.3
tò:rɔ̀	To break	128.9	134.2	241	190.1
	Sum	**1245**	**1141.9**	**2037.1**	**1717.6**
	Mean	**138.3333**	**126.8778**	**226.34444**	**190.8444**

[ó] high tone		M1	M2	F1	F2
máráúcíɛ̀l	Sixth one	130.9	120.1	203.3	213
àúcíɛ̀l	Six	143.8	130.8	226	222
ɔ̀mbó:lǒ	Vote	97.8	106.8	188	184.1
mányó:ró	A woman who has just given birth	101.9	108.1	195.6	191.4
cónɔ́rɛ́	Forcing (reflexive)	135.5	142.6	248	248
cólɔ́rɛ́	Paying (reflexive)	131.8	146.1	267	245
mórɔ́rɛ́	Warming (reflexive)	134.6	146	279	252
ɲàdìúcíɛ̀l	Six times	125.1	125.1	225	230
fó:lǒ	A kind of fish	97.8	118.8	225	195.3
	Sum	**1099.2**	**1144.4**	**2056.9**	**1980.8**
	Mean	**122.1333**	**127.1556**	**228.54444**	**220.0889**

[ò] low tone		M1	M2	F1	F2
kòlòndɛ̀:ŋ	Beetle	121.7	134.8	233	210
kòlòndɛ̀:ŋ	Beetle	113.1	127.9	219	198.6
cò:nɔ̀rɛ́	To force (reflexive)	112.9	123.1	218	186.4
cò:lɔ̀rɛ́	To pay (reflexive)	112.6	125.3	223	197.3
mò:rɔ̀rɛ́	To warm (reflexive)	115.8	114.6	211	191.8
lònyɔ̀rɛ́	To pluck out feathers (reflexive)	113.3	118.6	204.2	194.9
ɲòlɔ̀rɛ́	To swallow without chewing properly (reflexive)	107.6	121.6	203.3	194.3
lòwɔ̀rɛ́	To follow one another/ to follow (reflexive)	111.1	121	208	193.8
tòrɔ̀rɛ́	To break (reflexive)	110.8	122.1	210	186.9
	Sum	**1018.9**	**1109**	**1929.5**	**1754**
	Mean	**113.2111**	**123.2222**	**214.38889**	**194.8889**

[á:] high tone		M1	M2	F1	F2
èròkámá:nɔ́	Thank you	116.3	106	191.9	189.8

ɟàwá:r	Saviour	138.3	103.8	188.3	196.3
má:ná	Just	123.4	112.8	205.9	189.3
má:nɔ́	That one	141.5	122.2	203.9	190.1
má:nɛ́	Which one	113.6	110.4	215	196.3
ɲá:kɔ́	Girl	114	106.4	211	207.1
ðá:kɔ́	Woman	116.4	113.1	211	196.2
ðá:nɔ́	Human being	112.1	111	207.1	196
má:ˈrá	Mine	124.6	121.1	228	221
	Sum	1100.2	**1006.8**	**1862.1**	**1782.1**
	Mean	122.2444	**111.8667**	**206.9**	**198.0111**

[à:] low tone		M1	M2	F1	F2
bà:jɔ̀	To roam/ go for a walk	111.2	105.4	200.4	190.8
tà:c	A weaved ring placed on the head to help balance a pot	110.4	111.4	190.4	185.3
rà:ŋgɔ̀	To check/ look	108.8	117.9	210	192.6
cà:nɔ̀	To plan	109.4	124.4	197.9	183.9
pà:rɔ̀	To think	131.3	108.3	188.4	186.1
pà:kɔ̀	To praise	130.9	126.4	197.5	180.4
dà:jɔ̀	Grand mother	119.3	105.9	190.8	181.8
hà:ðɔ̀	To eat hurriedly	126.8	96.2	205.8	195.2
cà:mɔ̀	To eat	119	124.1	201.5	183.2
	Sum	**1067.1**	**1020**	**1782.7**	**1679.3**
	Mean	**118.5667**	**113.3333**	**198.07778**	**186.5889**

[á] high tone		M1	M2	F1	F2
mì:já	Give me	113.5	117.1	217	211
mà:já	Snatch from me	118.3	115.8	212	207.3
cà:cá	My tea	122.3	115.4	224	206.7
ɔ̀:rá	My brother-in-law	127.3	112.3	214	206.1
kì:tá	My character	123.4	128.1	235	211
lì:má	Visit me	129.3	114.7	215	212
wè:ndá	My visitor(s)	132.4	111.7	216	218
dè:ndá	My body	123.4	113.3	199.3	205.6
sà:ndá	Mistreat me	126.4	115.5	215	207.9
	Sum	**1116.3**	**1043.9**	**1947.3**	**1885.6**
	Mean	**124.0333**	**115.9889**	**216.36667**	**209.5111**

[à] low tone		M1	M2	F1	F2
àgú:lú	Pot	99.8	118.6	178.4	207.9
àdí:tá	Basket	95.6	103.8	182.3	193
ràtè:ŋ	Black	131.6	116.3	209.3	192.4

ràbɔ̀ndɔ̀	Bald headed	127.2	110.9	182.3	190.1
bàrú:pé	Letters	121.7	110.3	192.4	192.8
ràpɔ̀:dɔ̀	Slim	128.6	117.7	192.3	187.6
kàmàgà:mbò	Name of a place	110.8	105.8	207.3	185.4
kàmàgà:mbò	Name of a place	112.1	96.1	193.3	184.8
àgʊ́átá	Calabash	106.8	118	169.7	179.8
	Sum	**1034.2**	**997.5**	**1707.3**	**1534**
	Mean	**114.9111**	**110.8333**	**189.7**	**190.4222**

Appendix 2

The lists below show the mean of the high and low tones on the vowels used in the study. The labels used instead of the name of each speaker is also given. This information is also captured in Graphs 16, 17 and 18.

A

IPA/ tone	i: high	ɪ: high	u: high	ʊ: high	a: high
M1	156.0778	126.6667	132.0667	122.0222	122.2444
M2	147.1667	132.4889	132.2889	122.1	111.8667
F1	239.6667	239.3778	237.3333	228.8889	206.9
F2	234.3333	211.3778	224.4111	201.6333	198.0111
Mean	**194.3111**	**177.4778**	**181.525**	**168.6611**	**159.7555**

B

IPA/ tone	i high	ɪ high	u high	ʊ high	a high
M1	136.5889	133.4111	127.8111	122.1333	124.0333
M2	127.7889	121.0111	125.0222	127.1556	115.9889
F1	239.3333	223.3111	216.8778	228.5444	216.3667
F2	226	207.2778	216.0111	220.0889	209.5111
Mean	**182.4278**	**171.2528**	**171.4306**	**174.4805**	**166.475**

C

IPA/ tone	i: low	ɪ: low	u: low	ʊ: low	a: low
M1	136.9778	136.6222	133.2778	138.3333	118.5667
M2	131.8222	125.8444	136.6222	126.8778	113.3333
F1	230	230.1111	251.8889	226.3444	198.0778
F2	212.9333	197.8333	189.3625	190.8444	186.5889
Mean	**177.9333**	**172.6028**	**177.7879**	**170.6**	**154.1417**

D

IPA/ tone	i low	ɪ low	u low	ʊ low	a low
M1	127.2111	122.6556	113.3667	113.2111	114.9111
M2	117.6111	115.0889	125.7222	123.2222	110.8333
F1	209.3444	201.4556	223.6778	214.3889	189.7

F2	203.2111	197.5111	186.3556	194.8889	190.4222
Mean	**164.3444**	**159.1778**	**162.2806**	**161.4278**	**151.4667**