Macrolinguistics, Vol.10 No.2 (Serial No.17) 2022, pp.103-124
DOI: 10.26478/ja2022.10.17.5 © 2022 The Learned Press

Analysis of Second and Third Formant Locus Pattern and C-V Coarticulation in EkeGusii

Peter Nyansera Otieno[*]
(Kisii University, Kenya)
Evans Gesura Mecha[**]
(Kisii University, Kenya)

Abstract: This study analyses locus equations and regression lines relating to second and third formants as a measure of co-articulatory influence of vowels following stop consonants in EkeGusii. Coarticulation can be represented statistically using a schematic representation of locus equations by tracking consonant-vowel (CV) transition as a useful tool in the discrimination of place of articulation. Acoustic data was collected using Praat version 6.0 from four males and four females, native speakers of EkeGusii. Locus equations for the eight speakers were derived from CV words with intervocalic voiceless bilabial /p/, voiceless alveolar /t/ and voiceless velar /k/ preceding vowel /i/, /a/ and /o/ contexts. Scatter plots of locus equation of F2 and F3 onsets-F2 and F3 midpoints revealed patterns for each of the three voiceless stops in EkeGusii. The strongest degree of coarticulation is reported for velars then bilabials and the least degree of coarticulation with alveolars.
Keywords: locus equation, Praat, F2 transition, F2 target, coarticulation, EkeGusii, scatter plots, acoustic data

1. Introduction

To analyze coarticulation in this study, the second formant and third formant frequency, F2 and F3, transitions were investigated. F2 transition correlates with the place of articulation of consonants in that it varies with the neighboring vowel. The F2 frequency change and direction are difficult to attribute to a particular place of articulation since the degree of rising and fall depends on neighboring vowels (Harrington, 2011:121). Locus equations can be used to measure the coarticulatory influence of a vowel on a preceding

[*] Dr. Peter Nyansera Otieno: Lecturer and Senior Language Laboratory Technologist, Department of Languages, Linguistics and Literature, Kisii University, Kenya. E-mail: potieno@kisiiuniversity.ac.ke.
[**] Dr. Evans Gesura Mecha: Senior Lecturer, Department of Languages, Linguistics and Literature, Kisii University, Kenya. E-mail: evans-mecha@kisiiuniversity.ac.ke.

plosive. What is aimed at here is a vowel target that is least influenced by consonantal context and most similar to citation-form production of the same vowel. This is usually a vowel mid-point, the most steady-state part of the vowel where the vowel formants, and hence the phonetic quality, change minimally. In many cases, it has been observed that vowel targets could shift proportionally because of coarticulation. According to Agwuele *et al.* (2009:194) modified locus equations can also account for rate-induced vowel reduction effects and as cues for predicting frequencies of F2 transition onsets in rapid speech.

Locus equations were first used by Lindblom (1963) and later among others Sussman (1994), Sussman *et al.* (1991), Agwuele *et al.* (2009). Fruchter & Sussman (1997:2997) state: "Locus equations are linear regressions of the frequency of the second formant transition sampled at its onset (F2 onset) on the frequency of the second formant sampled in the middle of the following vowel (F2 vowel) for a single consonant coarticulated with a range of vowels. The F2 onset is plotted on the *y* axis and the F2 vowel on the *x*-axis."

Locus equation coefficients, slope, and y-intercept can be relied upon as accurate descriptors for a place of articulation for all stop consonants as reported by Sussman (1994) for American English; Fowler (1994) demonstrated how both the slope and y-intercept can be used as co-dependent variables in a multivariate analysis. The slope on its own was seen to be directly proportional to the articulation that takes place between a consonant and the following vowel (Sussman & Shore, 1996:2).

The purpose of this study was to add up to the literature the usefulness of F2 trajectory at vowel onset and vowel target as descriptors of a consonantal place of articulation. The majority of the studies done are in European languages. This study was on an African Bantu language, opening a window for supplying descriptions for less-studied languages like EkeGusii.

More crucially, the results of this experimental phonetics study can be used to explain and be the basis for further investigation of the nature and characteristics of coarticulation and other phonological processes outside the scope of the present study. The data can be used to show the interrelatedness of speech segments within the sound system of EkeGusii.

2. EkeGusii

This is a Bantu language spoken by Aba-Gusii (translated as 'the people of Gusii') found in Kisii and Nyamira counties in the South-West of Kenya. The Gusii are believed to be descendants of Mogusii who are said to have moved from the Congo basin into present Kenya through Uganda (Ochieng', 1974). EkeGusii is classified as E42 and is related to other Bantu languages like Kuria, Logooli, and Ameru. According to Mecha (2006) and Bosire (1993), the language has two distinct dialects, Ekerogoro (which is dominant) and Ekemaate. EkeGusii sound system as per Cammenga (2002) has remained largely understudied and this study is part of a project attempting to supply literature on the description of the language as the basis for other studies into the language.

According to Otieno *et al.* (2020), this language has seven monophthongs as /i e ɛ a ɔ o u/ with length distinction, that is, for every short vowel in the language, there is a corresponding long vowel. It must also be noted here that vowel length is phonemic in EkeGusii. Whiteley (1965) identifies EkeGusii consonants as follows: [β ɣ m n ʧ ŋ ɲ ɾ s t ɰ j p]. The IPA chart of EkeGusii would then look like as shown below:

Table 1. EkeGusii consonant chart

	Labials	Labiodentals	Alveolars	Palatals	velars
Plosives	p		t		k
Nasals	M		n	ɲ	ŋ
Flaps			ɾ		
Fricatives	B		s		ɣ
Approximants				j	ɰ

EkeGusii has a voiceless palatal affricate [ʧ] as in *chaka* ([ʧaka],'start').

Languages differ significantly in their syllable structure. EkeGusii allows just one consonant in onset and none in the coda. Every word in EkeGusii ends in a vowel. The EkeGusii syllable can be represented in a tree diagram for the word *nchwo* /nʧɰɔ/ 'come' as Figure 1.

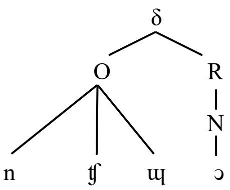

Figure 1. A tree diagram for *nchwo*

EkeGusii does not have a coda after the nucleus since every syllable ends in a vowel. For the two constituents, the nucleus is obligatory while the onset is optional. When in other languages like English the nucleus must not always be a vowel (Davenport & Hannahs, 2005), but in EkeGusii the nucleus must be a vowel.

3. Methodology

3.1 Subjects and stimulus materials

Four male and four female speakers were sampled for this study. Their ages ranged from 20 to 42, with an average age of 30.6. The sampled subjects were people with normal hearing and speech, and native speakers of the language. The linguistic environment of EkeGusii speakers is bilingual; speakers have EkeGusii as their mother tongue, and as soon as they start formal schooling, Kiswahili and English are introduced gradually. Kiswahili, a Bantu language, is the most dominant lingua franca in East and Central Africa, even in parts of Southern Africa like Malawi, Mozambique, and Zambia.

The 8 sampled talkers were selected after Ladefoged (2001), where three males and three females can suffice. Two dialectal variations were present in the subject pool; speakers of Ekerogoro and Ekemaate dialects of EkeGusii. Table 1 and example (1) give a list of words and carrier sentences that were used to generate oral data from the informants (Otieno & Mecha, 2019). See the carrier sentences to be used in the analysis of EkeGusii vowels and stops with highlighted target words (Otieno & Mecha, 2019) as in example (2).

(1) a. *pi**pi**pi* ([pi**pi**pi], 'completely')
*pa**pa**pa* ([pa**pa**pa], 'very hard')
*po**po**po* ([po**po**po], 'ideophone')

b. *ti**ti**ti* ([ti**ti**ti], 'very black')
*a**ta**ta* ([a**ta**:ta], 'break into small pieces')
*o**to**to* ([o**to**to], 'type of vegetable')

c. *i**ki**ki* ([i**ki**:ki], 'bring down repeatedly')
*a**ka**ka* ([a**ka**:ka], 'beat/thrash')
*O**ko**ko* ([o**ko**ko], 'name of a person')

(2) a. *Akoripi**pi**pigakiyonsipipi*. ([akoɾipi**pi**piɣakijɔnsipi:pi], 'He finished (everything).')
*Akang'apa**pa**pataripaapaa*. ([aka nŋapa**pa**pataɾipa:pa:], 'Hit like (ideophone).')
*Ebipoopobikagwang'apo**po**po*. ([eβipo:poβikagwanŋapo**po**po], 'The pawpaws fell like (ideophone).')

b. *Tebati**ti**titaritiiti*. ([teβati**ti**titaɾiti:ti], 'Say titi and not tiiti.')
*Roratata**ta**ataesani*. ([ɾɔratatata:taesani], 'See that dad does not break the plate.')
*O**to**toneyotooto*. ([o**to**tonejoto:to], 'Ototo is good for you.')

c. *I**ki**ikigaki, ikibionsi*. ([i**ki**:kiɣakiikibionsi], 'Please bring all down.')
*Ing'a aka amona**ka**aka*. ([Inŋa aka amonaa**ka**:ka], 'Give me this and this one.')
*Aka o**ko**konokooko*. ([Aka o**ko**konoko:ko], 'Raise an alarm with Okoko.')

As much as possible, the words in citation form were the same target words in carrier sentences. This was done to eliminate any intervening variable that could be caused by a different context. Since adjacent sounds affect each other anteriorly or posteriorly (Clements, 1985), in a CV context devised for this study all the plosives have a stable place of articulation affected only by the following vowel.

Each word and sentence was repeated three times for the three vowels. Thus, a total of 432 tokens were analyzed (3 consonants × 3 vowels × 3 repetitions × 8 subjects = 216 tokens × 2 (for word list and carrier sentences)). Each locus equation regression was generated separately for females and males.

3.2 Data points

Measurements of loci for F2 and F3 vowel onset and F2 and F3 vowel midpoint were done manually by inspecting the waveforms and spectrograms. To derive Locus Equations, F2 or F3 measurements were taken at two points, that is, at the onset of a vowel usually at the boundary marking the beginning of a vowel segment following a stop consonant, and F2 or F3 midpoint. The onset was measured specifically at the first glottal pulse where a clear F2 or F3 is discernible both on waveform and spectrogram. The second reading was taken at F2 or F3 midpoint, where F2 or F3 is seen as most stable, typically 60-100ms after the point at which the first measurement was taken (Everett, 2008).

For this study, the measurement was taken after Sussman & Shore (1996) based on visual inspection. F2/F3 onset points for vowels following the three stops in EkeGusii were the frequency of F2/F3 at the first glottal pulse of the vowel after the release of the burst. According to Otieno & Mecha (2019), EkeGusii is seen to have vowels with long resonances to the extent that if a standard midpoint is taken for all vowels, then the F2/F3 target will always be lower than the F2/F3 onset resulting in a flat LE scatter plot slope. A visual inspection of the formant was done to navigate through this situation. The earliest possible resonance after the stop burst release that was judged to continue F2/F3 of the vowel was taken as F2/F3 onset, that is, the first glottal pulse corresponding to the initial pitch period of the vowel. After that, F2/F3 target readings are done where the formant is steady or stable just before the point where the pitch track begins to plummet.

3.3 Recording

All the recording was made at the language laboratory at Kisii University. The lab is not attenuated. So, there was a little ambient noise among other noises from the environment. Efforts were made to control the noise as much as possible like making the recordings very early before the habitual bustle after eight o'clock. Each subject was made to sit on a chair facing a computer screen with the headphone attached to a microphone adjusted at about 15 cm from the mouth and inclining at about 45 degrees to avoid direct turbulence. The recording was made with a Weile WL-906 microphone and subjects spoke directly into the computer as the recordings were saved to the hard drive of the PC, using Windows 7, at a sampling rate of 44100 Hz.

3.4 Statistical data analysis

The acoustic measurements that form the quantitative data for this research, second and third formants (F2 and F3) were recorded in Excel spreadsheets and were statistically examined to compute (i) measures of dispersion, (ii) variance, and (iii) correlation. The mean and standard deviation of the different groups based on gender and place of articulation was calculated. To check whether the group results could be confirmed by individual results, individual results were computed. To check whether there are significant differences between the means of different variables and groups, a paired sample T-test (vowel duration in different contexts) and univariate analysis of variance were conducted. The use of statistics here follows work such as Forrest, Weismer, Milenkovic & Dougall (1988).

The basis for carrying out a T-test was to look for any significant difference between the two various sets of data. T-test eliminates any bias during the analysis of data and in conclusion, it tells us whether the sets of data are significantly different or not. In this research, there are two groups of informants, adult males, and adult females. What this entails are the questions of whether the data are significantly different or it is just random and whether there is not much difference after all. A value smaller than the critical value sought, for example, $p < 0.05$, means that there was a less than five percent chance that the data set are random but greater than ninety-five percent chance that the data were significantly different. If, on the other hand, the p-value was greater than five percent ($p > 0.05$), the meaning is a five percent chance that the data is random and less than ninety-five percent confidence that the data set were truly significant. So, when calculating this T-test, we need to see whether it is greater or less than the critical value because that will indicate the probability that the data sets were just random and there was no significance. In any set of data that we are using, we want as much confidence as possible hence a very small p-value to show that the data are not random but significantly different.

4. Results

4.1 Results for /p/

The results presented and analyzed below are categorized separately for males and females. This is because the males and females have different frequency ranges (see Otieno & Mecha, 2019) for a fuller discussion. The following are results for male speakers for the bilabial plosive /p/. Table 2 below displays the values for male informants as a group where k=slope and R^2= R squared.

Table 2. F2 locus equation averages for voiceless stop /p/ of four EkeGusii male speakers

male	k	y-intercept	R^2
pi	0.836	467	0.481
pa	0.715	451	0.816
po	0.905	311	0.691
M	0.819	410	0.663
SD	0.096	86	0.169
SE	0.056	49	0.098

The equation in the table above indicates a steep slope average of 0.82 with a positive y-intercept and r^2 R^2 of 0.6. Figure 2 shows the plots for all the 36 tokens for /pi pa po/.

All the tokens for the male informants plotted on the graph in Figure 2 showed a steep slope that was an indicator of high stop and following vowel coarticulation. That is, there was a close similarity of F2 onset values to F2 midpoint values for the vowels following /p/

for the male speakers. The vowels in a CV sequence could be influenced differently by the stop consonant /p/. The plotted tokens and regression lines for the separate vowels for male speakers indicated locus equation variations.

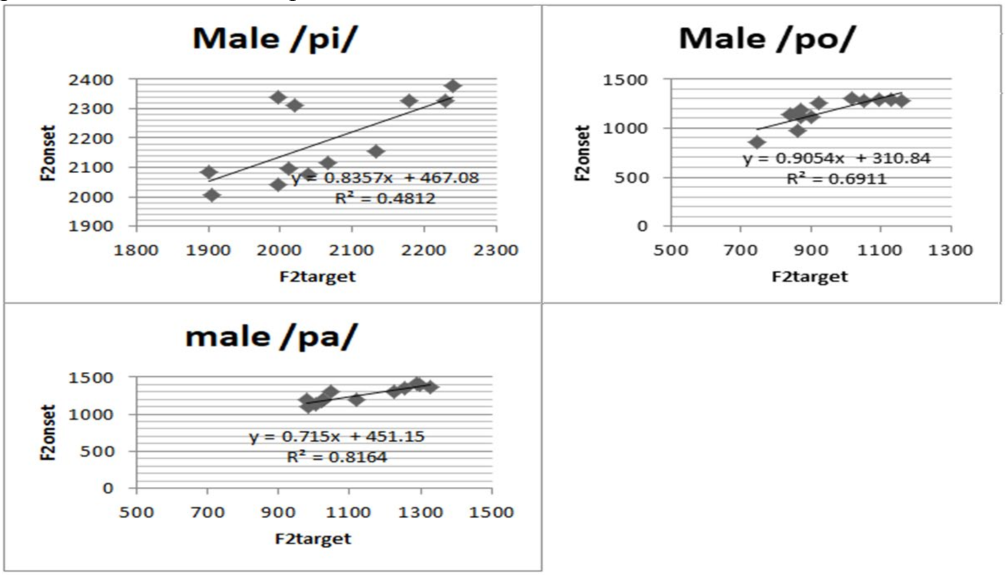

Figure 2. F2 locus equations, with plotted tokens and regression line for male subjects' /pi pa po/

The regression line is the steepest for /po/ with slope at 0.9 and y-intercept at positive 310Hz which translates to F2 onset being lower than the F2 target. The meaning is that /po/ for males showed a higher degree of coarticulation than /pi/ which was followed by a slope of 0.84 and the one with the least slope is /pa/ with a slope of 0.72. This confirms the idea that F2 rising and fall are also dependent on the following vowel after the stop consonant. Also, values for the slope and y-intercept are inversely related in that the steeper the slope the lesser the y-intercept and vice versa.

The above results for F2 can be compared with those of F3 as seen below. The slope and the linear fit were derived from the average measures. From the literature, formants following bilabial stops are expected to keep rising from vowel onset to vowel target position as a result of opening lips which when closed repress any rise in the formants (Stevens *et al.*, 1999).

Table 3. F3 locus equation averages for voiceless stop /p/ of four EkeGusii male speakers

Male	k	Y-intercept	R^2
pi	0.914	375	0.882
pa	0.615	1092	0.697
po	0.665	802	0.061

M	0.731	756	0.547
SD	0.160	361	0.431
SE	0.092	209	0.249

The average slope is 0.7 which is relatively steep. The data indicates a continual rise from the vowel onset point to the vowel target position. This indicates a higher magnitude of coarticulation of bilabials as captured by the regression lines of F3. The formant frequency is seen to keep rising since, during the closure, the formant is depressed and at release, the formants rise steadily. However, the slope is slightly less steep as compared to that of F2 above.

Figure 3 below shows the plots presented in the data above.

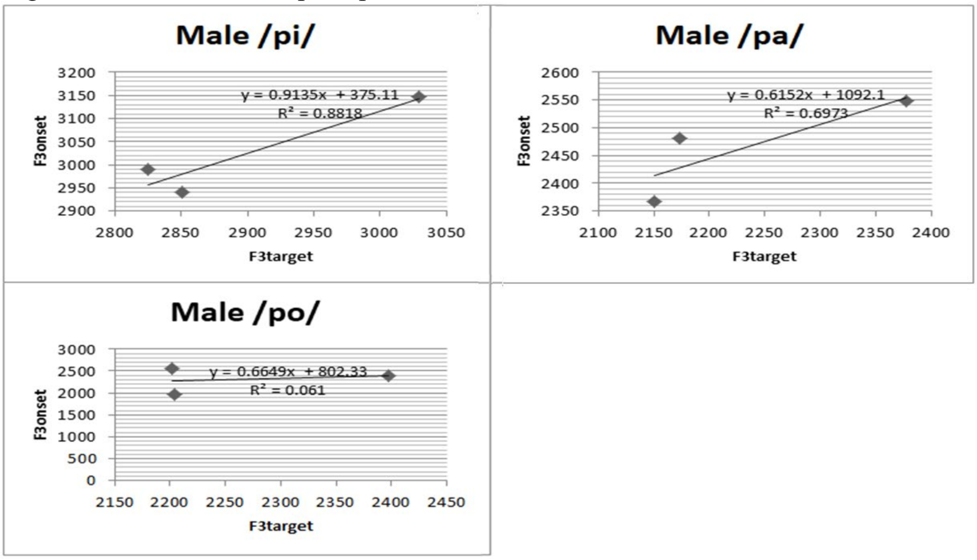

Figure 3. F3 locus equations, with plotted tokens and regression line for male subjects' /pi pa po/

The following are the results for female informants for this study.

Table 4. Locus equation for voiceless stop /p/ of four EkeGusii female speakers

Female	k	y-intercept	R^2
pi	0.862	425	0.693
pa	0.829	306	0.726
po	0.952	104	0.414
M	0.881	278	0.610
SD	0.064	162	0.171
SE	0.037	94	0.099

The table above can be displayed better in a graph showing the locus equation, plotted tokens, and regression line as in Figure 4.

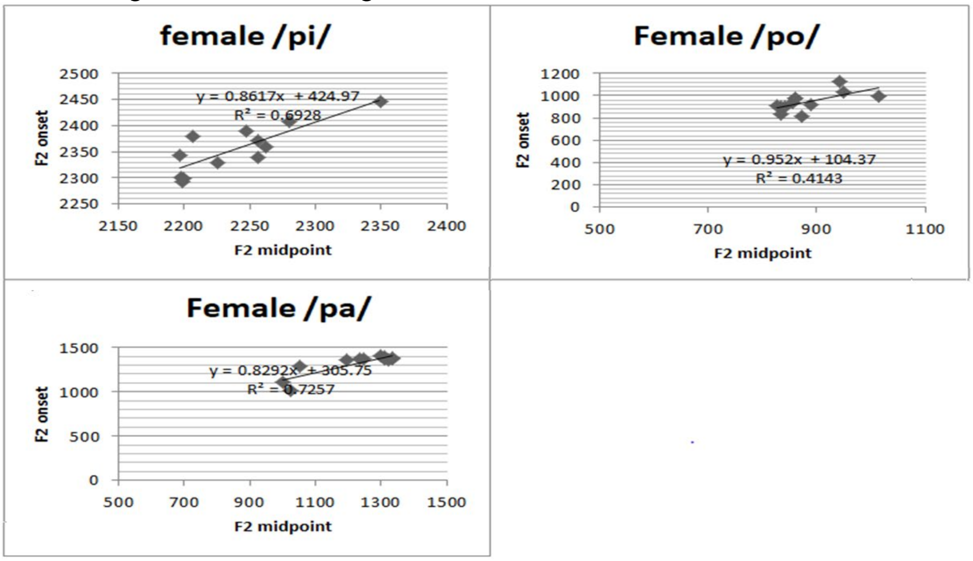

Figure 4. F2 locus equation, with plotted tokens and regression line for the female subjects for /pi pa po/

The slope was slightly above the values for males 0.88 with a y-intercept of 278 and an r-squared value of 0.61. This shows that the slope was slightly steeper than that of the males and that the stop consonant /p/ was coarticulated with the following vowels. Just like the males above, coarticulation levels varied depending on the vowel coming after the bilabial stop. The same order as that of males was reported for females with /po/ being the steepest followed by /pi/ and the least was /pa/.

The slight differences between male and female values for /p/ were attributed to the differences in the vocal tract between males and females where males have a longer and more massive tract reducing the F2 frequency of the vowels. The difference between them was however not statistically significant (p-value=0.065) meaning that the slope, y-intercept, and r^2 R^2 values could not discriminate between female and male data.

The data also presents low standard deviation and standard error values. This means that there is no great dispersion when we consider all the tokens together.

For F3, the slope and regression fit were as captured in Table 5 and Figure 5 below.

Table 5. F3 locus equation for voiceless stop /p/ of four EkeGusii female speakers

Female	k	Y-intercept	R^2
pi	0.974	118	0.537
pa	0.653	968	0.733
po	0.943	134	0.203
M	0.857	407	0.491

SD	0.177	486	0.268
SE	0.102	281	0.155

Table 5 indicates a steeper slope for female talkers as compared to males. SD and SE values are small indicative of less dispersion of the values when all the 36 tokens are compared. The same can be displayed more graphically in the graphs below.

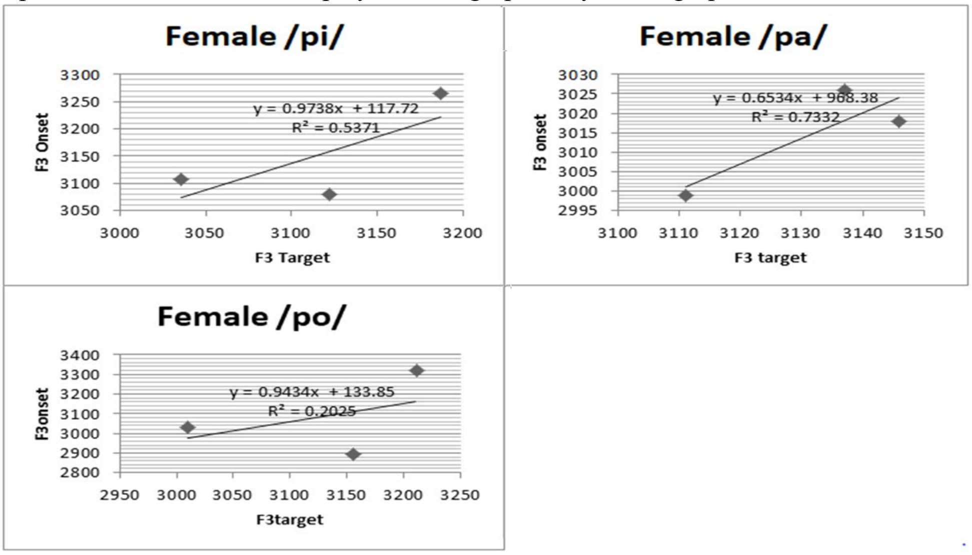

Figure 5. F3 locus equation, with plotted tokens and regression line for the female subjects for /pi pa po/

The data above seem to contradict the notion that formants following bilabial stops tend to rise from onset to full vowel realization. In the data, there is an actual reduction of formant values from the onset of the vowel especially the combination /po/.

4.2 Results for /t/

In the following section, locus equations for the eight speaker's tokens for /t/ are presented. The graphs and regressions allow us to make observations about the trajectory of the regression line as it relates to coarticulation. The following are results for male subjects.

Table 6. F2 locus equation for voiceless stop /t/ of four EkeGusii male speakers

male	k	y-intercept	R^2
ti	0.629	917	0.758
ta	0.639	201	0.863
to	0.647	569	0.169
M	0.648	562	0.597
SD	0.010	358	0.374
SE	0.006	207	0.216

Table 6 above gives a less steep slope of averagely of 0.648 and a positive y-intercept of 562 Hz. This means that in the majority of the tokens, F2 onset values were lower than F2 midpoint values. Also, the data shows lower SD and SE meaning that many values were concentrated and not much dispersed. This is better exemplified in the plots in Figure 6.

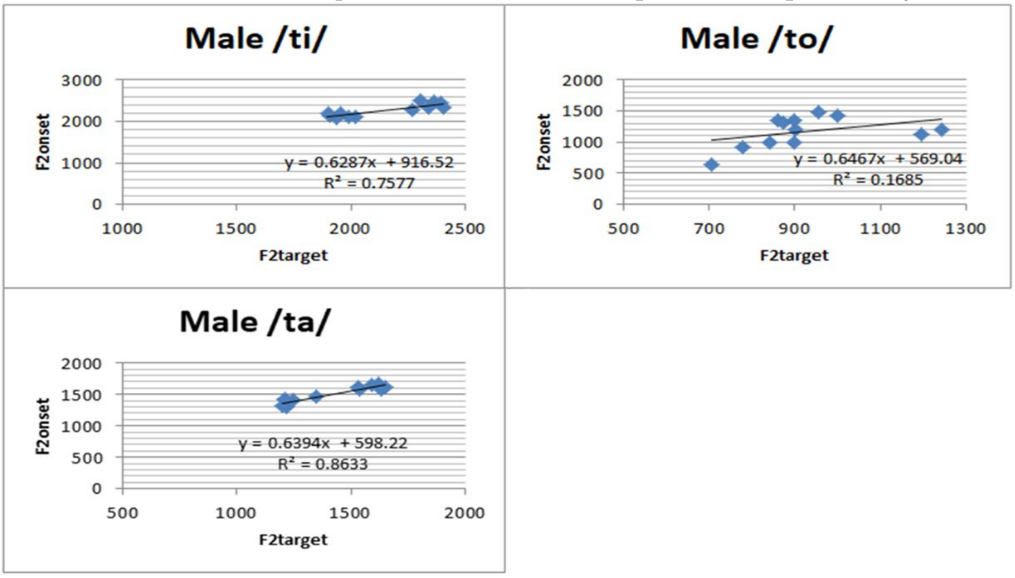

Figure 6. F2 locus equation, with plotted tokens and regression line for male subjects /ti ta to/

From the graph in Figure 6, we can observe that the slope is less steep at 0.648 compared to the values for /p/ (see section 4.1 above). Apart from this general observation, various CV sequences influenced F2 trajectories in a slightly different way depending on the following vowel after /t/ though the difference was not statistically significant.

The values indicate that for /ti/ F2 onset was consistently lower than the F2 target value. The difference between F2 onset and F2 midpoint was larger than that reported for /p/ for both males and females. The slope is slightly steeper for /to/ with a slope of 0.647 and a y-intercept value of positive 569. This also indicated a lesser coarticulation between /t/ and the following vowel being below 0.81 for high coarticulation (Sussman & Shore, 1996). It was followed by /ta/ at 0.64 and the least was for /ti/ at 0.63.

The results for F2 regression fit can be complemented with those of F3 as seen below in Table 7 and Figure 7.

Table 7. F3 locus equation for voiceless stop /t/ of four EkeGusii male speakers

Male	k	Y-intercept	R^2
ti	0.304	2228	0.116
ta	0.491	1433	0.659

to	0.305	1699	0.639
M	0.367	1787	0.471
SD	0.108	404	0.308
SE	0.062	234	0.178

This table shows very large y-intercept figures and equally large SD and SE figures that point to a great dispersion of the figures. Again, the slope tends to be flat indicating less coarticulation between the stop consonant and following vowels. We can visualize this better in the plots in Figure 7 below.

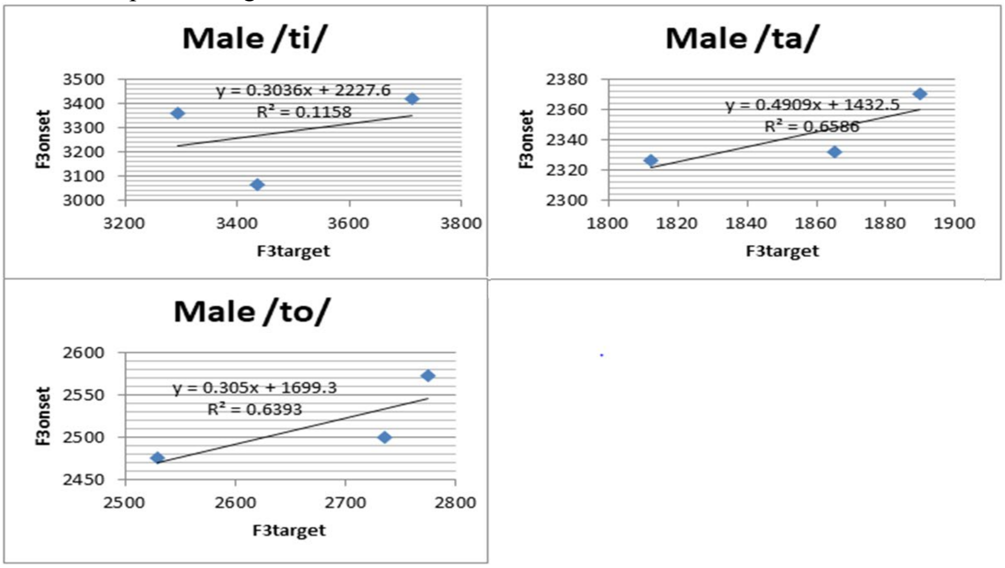

Figure 7. F3 Lolus equation, with plotted tokens and regression line for male subjects /ti ta to/

The plot shows a less steep slope than that of the F2 plot. The following are the results of the female speakers.

Table 8. F3 locus equation for voiceless stop /t/ of four EkeGusii female speakers

female	k	y-intercept	R^2
ti	0.629	889	0.183
ta	0.671	624	0.327
to	0.676	291	0.469
M	0.670	601	0.326
SD	0.041	300	0.143
SE	0.024	173	0.082

The slope for the females was slightly steeper than that of the males with positive y-intercept values which is indicative of the idea that F2 onset values were consistently lower than the F2 midpoint values for all tokens. The following graph and plotted tokens in Figure 8 for females illustrates this better.

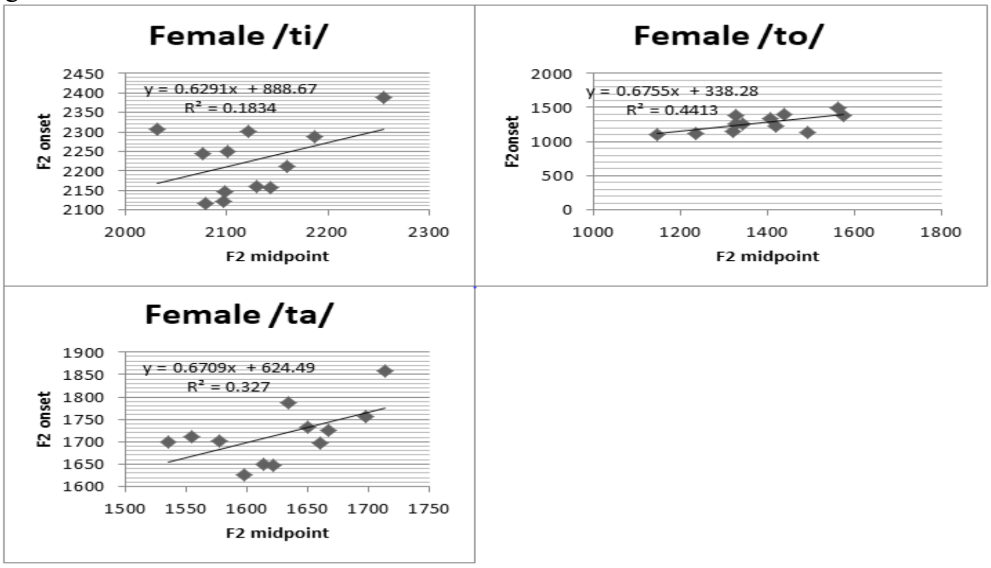

Figure 8. F2 locus equation, with plotted tokens and regression line for female subject's /ti/, /ta/ and /to/

Locus Equation results posted by female informants are similar to those posted by the male counterparts with a slight variation that was not statistically significant. This is seen from Figure 8 locus equation graphs with plotted tokens for each CV sequence as got from female speakers.

Females show a variation of coarticulation between an alveolar plosive and the following vowel. Females have the greatest disparity between F2 onset and F2 midpoint of vowel following alveolar consonant /t/ for /i/ with a regression line having a less steep slope of 0.62 followed by the slope of /a/ with 0.671 and /o/ with the steepest slope of 0.676 in this series. It should be noted too that the less steep the slope the higher the y-intercept value.
Generally, reduced coarticulation associated with /t/ is also supported by higher y-intercept values and a less steep slope. For these EkeGusii females and male speakers, reduced proximity between vowel F2 onset and F2 midpoint following alveolar plosive is witnessed. Variations observed in the locus equations as vowels are changed from /ti/, /ta/, and /to/ reflect the constriction of the oral cavity during the production of the alveolar plosive. As /ti/, /ta/, and /to/ are considered separately for F2 onset and F2 midpoint, characteristic tongue movement from an alveolar place of articulation to the target position associated with the following vowel. /t/ affects F2 onset values: for /i/ F2 values are extremely high hence occurring at the leftmost part of the regression lines whereby F2 onset values are less than vowel F2 midpoint values; for the tokens of the /a/ vowel, they typically have very

high F2 values hence occupying the left-most part of the regression lines as seen on Figure 8. The low F2 values are consistent with the smaller constriction size of the oral cavity associated with the preceding /t/ plosives. The same oral cavity configuration does not hold for tokens of /i/ and /o/ vowels which are higher as compared to those of /a/. These F2 loci are typical of the locus equations associated with /t/ in EkeGusii which also attests to the locus equations in the literature.

The trajectory for F3 loci is related to that of the F2 even if the slope is less steep and the y-intercept figure is large as seen in Table 9 and Figure 9 that follow.

Table 9. F3 locus equation for voiceless stop /t/ of four EkeGusii female speakers

Female	k	Y-intercept	R^2
ti	0.170	2508	0.987
ta	0.480	1731	0.114
to	0.333	4188	0.001
M	0.328	2809	0.368
SD	0.155	1256	0.538
SE	0.090	725	0.311

There were obvious outliers in the entries. Yet, the general trend was maintained as compared to the males earlier observed. The regression line and graph for the above data are shown below.

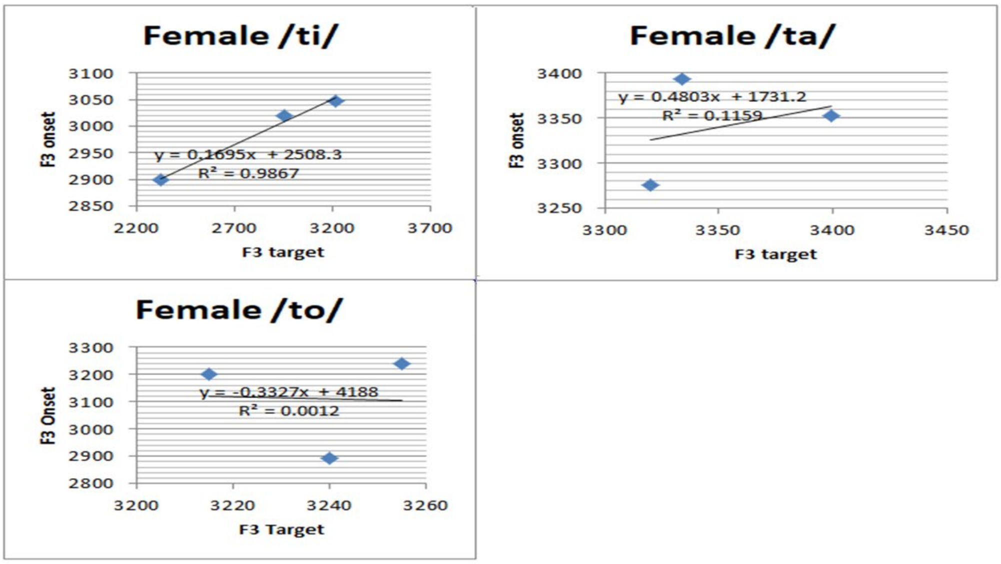

Figure 9. F3 locus equation, with plotted tokens and regression line for female subjects' /ti/, /ta/ and /to/

The almost flat slope is typical of vowels in EkeGusii following alveolar stop consonant with very large figures of the y-intercept and small r-squared figures.

4.3 Results for /k/

Having looked at the locus equations data for /p/ and /t/, we will now turn to locus equations for /k/. Generally, locus equations for /k/ have a slope value nearing 1.0 which is indicative of a high degree of /k/-V coarticulation. Table 10 gives the results of the male subjects.

Table 10. F2 locus equation for voiceless stop /k/ of EkeGusii male speakers

male	k	y-intercept	R^2
ki	0.917	23	0.794
ka	0.942	76	0.899
ko	0.953	22	0.944
M	0.937	40	0.879
SD	0.019	30	0.077
SE	0.011	17	0.045

The slope for /k/ was very steep close to 1.0 and a small y-intercept value of negative 40. The R-squared value is also high at 0.879. The following graph with plotted tokens for /k/ for male subjects.

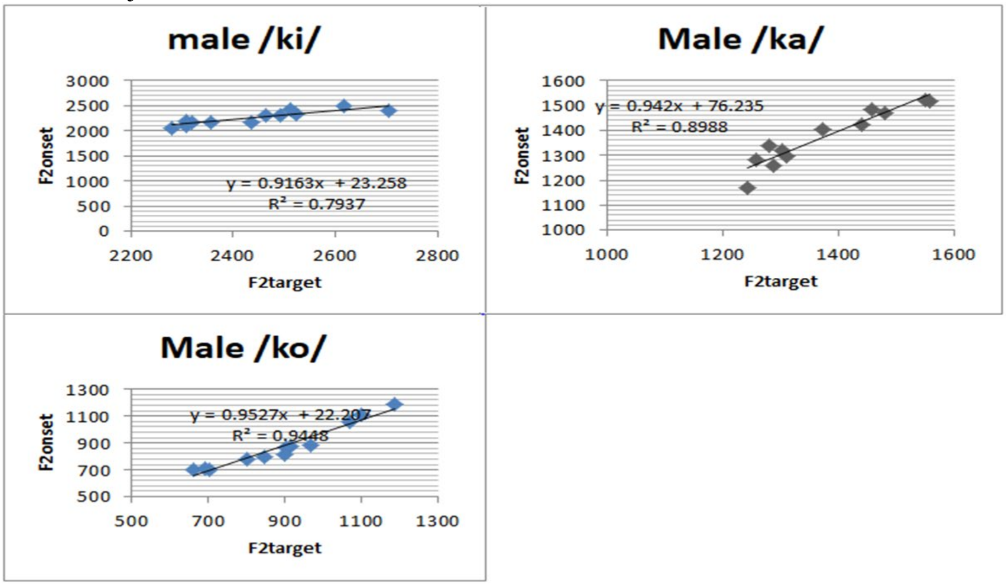

Figure 10. F2 locus equation, with plotted tokens and regression line for male subjects' /ki/, /ka/ and /ko/

However, despite the steep slope posted by the male informants here, the correlation between the F2 onset and F2 midpoint keeps changing since the y-intercept is at about -13 Hz. This means that some tokens have F2 onset values higher than the F2 midpoint.

The variations in the locus equations for /ki/, /ka/, and /ko/ are indicative of the influence that /k/ has on the following vowel. The slope for /ka/ is so steep indicating a negligible disparity between F2 onset and F2 midpoint. This could be as a result of consonant place of articulation and height of vowel which approximate easily; there is a minimal alteration of jaw height and tongue position from the articulation of /k/ to the articulation of /a/. For /ko/ the slope is at 0.9527 and /ki/ the slope is 0.9163, all steep slopes suggestive of more coarticulation, in degrees of course.

We now compare the results above with those of F3 as in the following Table 11.

Table 11. F3 locus equation for voiceless stop /k/ of EkeGusii male speakers

male	k	y-intercept	R^2
ki	0.913	244	0.996
ka	0.929	75	0.721
ko	0.918	68	0.944
M	0.920	129	0.887
SD	0.008	100	0.146
SE	0.005	58	0.084

F3 slope was at an average of 0.92, which is very steep indicative of high coarticulation between the stop consonant /k/ and the following vowels. The same results are approximated for F2 as seen earlier. A visual display of their linear regression can be seen below in Figure 11.

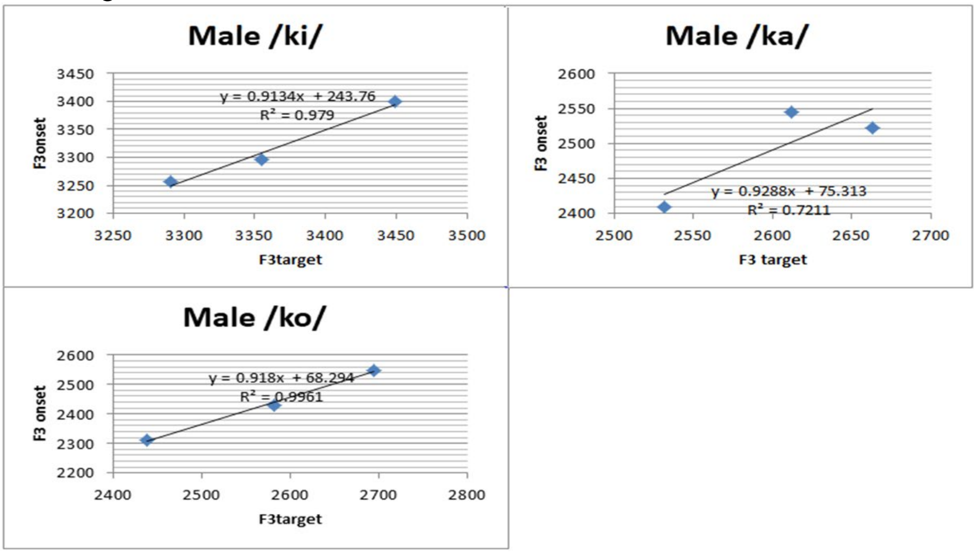

Figure 11. F3 locus equation, with plotted tokens and regression line for male subject's /ki/, /ka/ and /ko/

The following results are for the female subjects.

Table 12. F2 locus equation for voiceless stop /k/ for EkeGusii female speakers

Female	k	y-intercept	R^2
ki	0.901	212	0.482
ka	1.015	131	0.578
ko	0.986	19	0.724
M	0.949	121	0.595
SD	0.028	57	0.068
SEM	0.020	41	0.048

Table 12 can graphically be displayed for a better look at the locus equation and regression line in Figure 12 below.

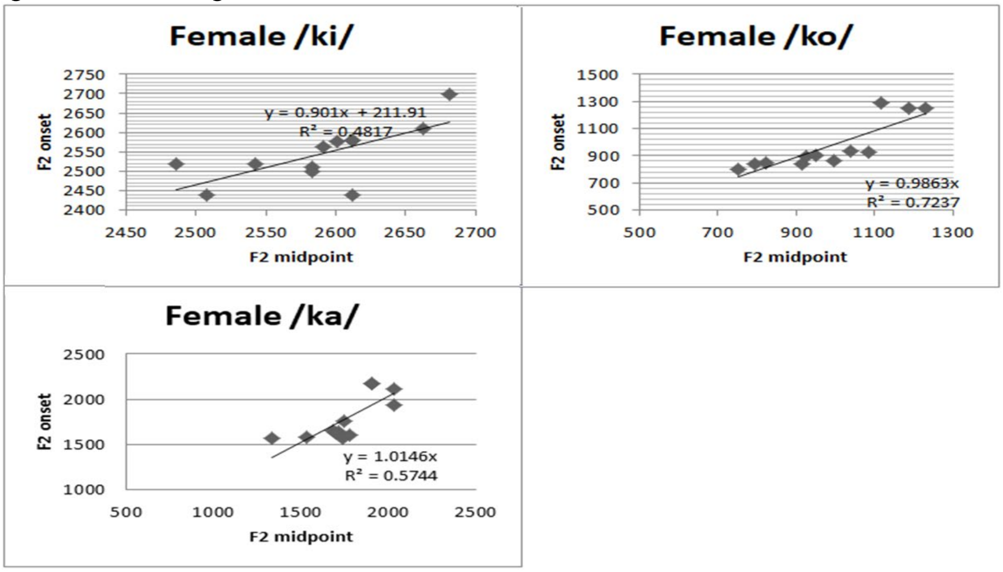

Figure 12. F2 locus equation, with plotted tokens and regression line for female subject's /ki/, /ka/, /ko/

The degree of coarticulation for the female speakers is not very different from that of the male speakers as the slope is 0.95 which nears 1.0. Though quite similar, the slopes of female speakers have some subtle differences from those of the males. Somehow, these differences could not be taken as cues for gender differentiation for the stop consonant as the differences were not statistically significant ($p>0.05$).

For female /ki/, the vowel F2 onset following /k/ was slightly lower than for /ka/ and /ko/ at 0.982. It is followed by /ko/ at 0.987 and the steepest slope was recorded for /ka/ at 1.01. The data gives evidence of proximity between F2 onset and F2 target.

F3 vowel formant following velar stop /k/ showed closer coarticulation as the slope was approximated at 0.899. This can be seen in Table 13 and Figure 13 below.

Table 13. F3 locus equation for voiceless stop /k/ of EkeGusii female speakers

Female	k	y-intercept	R^2
ki	0.905	263	0.971
ka	0.912	174	0.862
ko	0.880	352	0.926
M	0.899	263	0.919
SD	0.017	89	0.055
SE	0.010	51	0.032

This table can be displayed better in the graphs below.

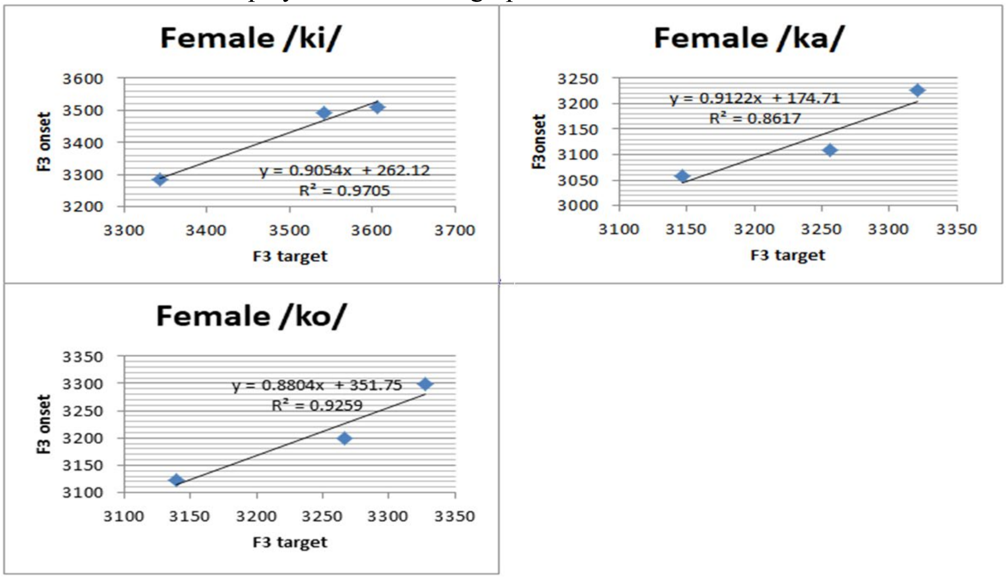

Figure 13. F3 locus equation, with plotted tokens and regression line for female subject's /ki/, /ka/, /ko/

Both males and females indicate the steepest slopes for /k/ followed by /p/ and the least steep slope was that of /t/. This was seen for both F2 and F3 trajectories.

5. Discussion

Research in empirically-based sound analysis relies heavily on the estimation of acoustic qualities to correctly estimate the place of articulation and degree of coarticulation. Locus equations have come in handy to help predict these attributes of phonetic features. The results of this study indicate that locus equations summarize some key aspects of formant transitions of preceding consonants utilizing straight-line relationships (Falek *et al.*, 2014). F2 and F3 transitions show slopes that are reflective of a consonant place of articulation.

In the present study, locus equations (LE) were derived from F2 and F3-onset against F2 and F3-target points for vowels following the three voiceless stop consonants in EkeGusii in an experiment geared towards determining whether LE can be used as phonetic descriptors of the place of articulation to set apart the three EkeGusii stop consonants /p/, /t/ and /k/. Three vowel contexts of /i/, /a/, and /o/ were used in a CV combination with the voiceless plosives.

F2 and F3 onset measures were taken at the first glottal pulse and F2 and F3 target readings were made at the point where F2/F3 formants were most stable after a physical inspection of the formant trajectory (after Sussman & Shore, 1996). The two points were then recorded for every token, their means and standard deviation calculated per subject, and then as a group.

Locus Equation data presented above rest on the foundation that speech segments happen together in connected speech and that they affect each other. The influence speech segments in the data for this study exerting on their neighbours is varied in degrees (Velonec, 2015). This is due to articulatory adaptations that take place during the intercourse of an utterance, which is referred to here as coarticulation.

Continuous speech allows phoneticians to use instrumental means to theorize on articulatory phonetics. As Recasens (2006) notes, there is a succession of articulatory movements in that as one articulatory movement is in progress, another for an adjacent segment sets in. Since the segments, depending on the place of articulation for stop consonants and tongue height and shape of lips for vowels, are varied, we have varying effects as revealed by the data presented above. Running speech from this perspective can never be taken as individual distinctive segments but a set of overlapping articulatory movements.

Results of this study gave insight into EkeGusii stop consonants and following vowel articulatory organization as brought out by LE gradients, R^2, and y-intercepts. Using these measurements in this study, the degree of overlap of articulatory gestures associated with speech segments through their acoustic effects was gauged (Keating *et al.*, 1980). During the production of EkeGusii velar plosive, the measurements reveal a steep slope of above 0.9 indicating high coarticulation between the velar and following vowel. The slope varies in steepness depending on the vowel involved. The variations in the locus equations for /ki/, /ka/, and /ko/ are indicative of the influence that /k/ has on the following vowel. Since there was no statistically significant difference between male and female data, the two data sets were collapsed and their average scores were computed. The slope for /ko/ is the steepest at an average of 0.979 indicating a negligible disparity between F2 onset and F2 midpoint. This could be as a result of consonant place of articulation and height of vowel which approximates easily; there is a minimal alteration of jaw height and tongue position from the articulation of /k/ to the articulation of /o/. For /ka/ the slope is at 0.942 and /ki/ the slope is 0.94 all steep slopes suggestive of more coarticulation, in degrees. The data points for other languages in the literature vary slightly from those of EkeGusii, reflecting the individuality of the language.

There is reduced coarticulation associated with /t/ as supported by y-intercept values and the least steep slope as compared to the values for /p/ and /k/. For these EkeGusii females and male speakers, there is no closer proximity between vowel F2 onset and F2 midpoint following alveolar plosive. Variations observed in the locus equations as the vowels are changed from /ti/, /ta/, and /to/ reflecting the constriction of the oral cavity during the production of the alveolar plosive. As /ti/, /ta/, and /to/ are considered separately for F2 onset and F2 midpoint, characteristic tongue movement from an alveolar place of articulation to the target position are associated with the following vowel. These F2 loci are typical of the locus equations associated with /t/ in EkeGusii which also attests to the locus equations seen in the literature (Velonec, 2015; Agwuele *et al.*, 2009).

The distinguishing element for /p/ is that the following vowels influence the slope and y-intercept points differently. The average slope for both males and females is 0.85. This is lower than that of the velar stop. The slope is steepest with /po/ at 0.9287 with a positive y-intercept of 0.534. The positive y-intercept means that F2 onset values are generally higher than the corresponding F2 midpoint values. Locus equations for /p/ tend to have low y-intercept values as reported by Zhang Hanbin (2017) for the Monguor language.

These results support the assertion of Everett (2008) that there are two types of coarticulation for /p/: lingual and labial. For lingual coarticulation, it seems that the tongue positions itself in anticipation of the height and backness of the following vowel as the preceding /p/ is produced. Labial coarticulation is a carry-over effect from the preceding labial to the following sonorant whereby we see the vowel F2 onset value consistently lower than the F2 midpoint value.

The data for EkeGusii showed strong evidence for place-dependent differences for the three-stop consonants just like the data for Graetzer *et al.* (2015). CV coarticulation data for this study separated bilabial, alveolar, and velar stops.

Again, results from the slopes followed a given order of steepness as noted also by Graetzer *et al.* (2015), Sussman & Shore (1996), and Velonec (2015) among others for other languages from the Americas, Europe, and Asia. The velar stop had the steepest slope followed by the bilabial stop and the least steep slope was seen with the alveolar stop. The extent of the slope could result from language-specific perceptual constraints and phonological processes together with other prosodic variables such as length and tone patterns in operation in EkeGusii, a subject for a future study.

Locus equation intercept is usually relative to the frequency of F2 at the vowel target. F2 at vowel midpoints varies depending on the consonant preceding the vowel. According to

Fant(1960), this is because average F2 at stop release is a consequence of tongue frontness and lip rounding as these two affect F2 most directly. Other phenomena may include C-V carryover coarticulation, the position of the tongue, and the shape of lips as the stop consonant is released.

6. Conclusion

Despite the subtle differences noted earlier between the values for males and females, the slopes and regression lines reported for both genders are quite similar. Inter-speaker differences can be investigated further to reveal deeper patterns of coarticulation for EkeGusii stop consonants. However, locus equations for all the female and male informants reveal uniquely similar patterns of EkeGusii CV coarticulation. Acoustic evidence emerges of patterns that correlate with the articulation of consonant-vowel interaction in EkeGusii in this study. The isomorphism witnessed attests to patterns that are EkeGusii specific.

No similar locus equation plots and regression lines exist in the literature for EkeGusii, which is a phonetically under-described language, or even for other Bantu languages related to EkeGusii. It is hoped that future phonetic studies will allow the comparison of these locus equation data with others. For the sake of this study, we can only observe the patterns of coarticulation as brought out by the locus equations of vowels F2 and F3 onset vs. F2 and F3 midpoints following EkeGusii stop consonants.

This study provides a good reference and basis for the study of EkeGusii phonetics and phonology. It falls within a larger project of EkeGusii language description and documentation by these researchers to avail literature in this under described language.

Abbreviations and symbols

C-V	Consonant-Vowel sequence	M	Mean (Average)
F1	First Formant	SD	Standard Deviation
F2	Second Formant	SE	Standard Error
F3	Third Formant		

References

Agwuele, A., H. M. Sussman & B. Lindblom. 2009. The Effect of Speaking Rate on Consonant Vowel Coarticulation [J]. *Phonetica*, 65:194-209.

Bosire, M. B. 1993. *Ekegusii: A comparative study of Rogoro and Maate dialects* [D]. Master's Thesis. Nairobi: University of Nairobi.

Cammenga, J. 2002. *Phonology and Morphology of Ekegusii: A Bantu language of Kenya* [M]. Koln: Rudiger Koppe Verlag.

Clements, G. N. 1985. The Geometry of Phonological Features [J]. *Phonology Yearbook*, 2:225-252.

Davenport, M. & S. J. Hannahs. 2005. *Introducing Phonetics and Phonology* [M]. London: Arnold.

Everett, C. 2008. Locus Equation Analysis as a Tool for Linguistic Fieldwork [J]. *Language Documentation and Conservation*, 2(2):185-211.

Fant, G. 1960. *Acoustic Theory of Speech Production* [M]. The Hague: Mouton.

Falek, L., O. Bouferroum, A. Djeradi & H. Teffahi. 2014. Analysis and Recognition of Arabic Consonants Using Locus Equations [J]. *Lecture Notes on Information Theory*, 2(1):72-77.

Forrest, K., G. Weismer, P. C. Milenkovic & R. N. Dougall. 1988. Statistical Analysis of Word-Initial Voiceless Obstruents: Preliminary data [J]. *Journal of the Acoustical Society of America*, 84:115-123.

Fowler, C. A. 1994. Invariants, Specifiers, Cues: An investigation of locus equations as information for place of articulation [J]. *Perception & Psychophysics*, 55:597-610.

Fruchter, D. & H. Sussman. 1997. The Perceptual Relevance of Locus Equations [J]. *Journal of the Acoustical Society of America*, 102(5):2997-3008.

Graetzer, S., J. Fletcher & J. Hajek. 2015. Locus Equations and Coarticulation in Three Australian Languages [J]. *Journal of the Acoustical Society of America*, 137(2):806-821.

Harrington, J. 2011. *Phonetic Analysis of Speech Corpora* [M]. Munich: Wiley-Blackwell.

Keating, P., J. Westbury & K. N. Stevens. 1980. Mechanisms of Stop Consonant Release for Different Places of Articulation [J]. *Journal of the Acoustical Society of America*, 67(Supp.1): S93.

Ladefoged, P. 2001. *A Course in Phonetics* [M]. Boston: Heinle and Heinle Thomson Learning.

Lindblom, B. 1963. *On Vowel Reduction* [R]. Speech Transmission Laboratory Report No. 29. Stockholm: Royal Institute of Technology.

Mecha, E. G. 2006. *The Phonology and Morphology of Ekegusii Reduplication: An optimality theoretic approach* [D]. Master's Thesis. Nairobi: Kenyatta University.

Ochieng', W. R. 1974. A *Pre-colonial History of the Gusii of Western Kenya from C.A.D. 1500 to 1914* [M]. Nairobi: East African Literature Bureau.

Otieno, P. N. & E. G. Mecha. 2019. Acoustic Analysis of Ekegusii Vowel System [J]. *Macrolinguistics*, 7(2):92-109.

Otieno, P. N., E. Mecha & N. Opande. 2020. An Acoustic Analysis of the Short and Long Vowels in Ekegusii Language [J]. *International Journal of Research and Scholarly Communication*, 3(1):4-20.

Recasens, D. 2006. Acoustic Analysis [A]. In W. Hardcastle (ed.). *Coarticulation: Theory, data, and analysis* [C]. Cambridge: Cambridge University Press.

Stevens, K. N., S. Y. Manuel & M. L. Matthies. 1999. Revisiting Place of Articulation Measures for Stop Consonants: Implications for models of consonant production [A]. In J. J. Ohala, Y. Hasegawa, M. Ohala, D. Granville & A. C. Bailey (eds.). *Proceedings of the 14th International Congress of Phonetic Sciences*, Vol.2 [C]. San Francisco: University of California, 1117-1120.

Sussman, H. M., H. A. McCaffrey & S. A. Mathews. 1991. An Investigation of Locus Equations as a Source of Relational Invariance for Stop Place Categorization [J]. *Journal of the Acoustical Society of America*, 90:1309-1325.

Sussman, H. M. 1994. The Phonological Reality of Locus Equations across Manner Class Distinctions: Preliminary observations [J]. *Phonetica*, 51:119-131.

Sussman, H. M. & J. Shore. 1996. Locus Equations as Phonetic Descriptors of Consonantal Place of Articulation [J]. *Perception and Psychophysics*, 58:936-946.

Velonec, V. 2015. Coarticulation [A]. In J. Davis (ed.). *Phonetics* [C]. New York: Nova Science Publishers, Inc, 47-86.

Whiteley, W. H. 1965. *A Practical Introduction to Gusii* [M]. Nairobi: East African Literature Bureau.

Zhang Hanbin. 2017. Coarticulation of Nasal Vowels in Monguor Language [J]. *Advances in Social Science, Education and Humanities Research*, 107:81-84.