Locus Equation Analysis as a Tool for Linguistic Fieldwork

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Locus equations are linear regressions based on F2 formant transitions from vowel onsets to vowel midpoints. The F2 value of the onset of a given vowel can be plotted on the y-axis, with the F2 for the vowel's midpoint plotted on the x-axis. Locus equations are derived from numerous F2 onset-F2 midpoint plots of this type. Each locus equation is associated with a particular consonant, which precedes the particular vowel tokens plotted according to F2 transition. Locus equations provide data on the patterns of CV coarticulation characterizing particular consonants. Studies in laboratory settings have demonstrated the efficacy of locus equation analysis for exploring such coarticulation patterns. However, locus equation analysis has generally not been exploited as a tool for linguistic fieldwork. This study presents an exception, as the author presents various locus equations based on data from Karitiâna, an endangered Amazonian language. These equations, based on acoustic data gathered in the field, reveal language-specific patterns of coarticulation. The results suggest that, even in remote non-laboratory settings, locus equations can be applied in a straightforward manner in order to provide useful insights into a language's sound system.

1. INTRODUCTION.[1] In investigating endangered languages in remote regions such as the Amazon basin, field linguists have often been restricted to transcription-based data in their phonetic and phonological descriptions. While obviously a crucial weapon in the field linguist's arsenal, transcription-based methodologies are limited to the extent that they are influenced by the field linguist's native language (cf. Strange 1995). Another limitation of employing transcription-based evidence alone is the difficulty of using transcriptions for exploring patterns found only in continuous-time data (cf. Port and Leary 2005). In part due to methodological constraints, sounds in a particular language are often treated as if they were discrete units in the speech signal. However, in actual speech, the productive and perceptual correlates of such supposedly discrete units are not in fact easily extractable from adjacent sounds. In other words, sounds are generally contextually variable, i.e., their articulatory and acoustic characteristics change somewhat in accordance with the properties of adjacent sounds. This is true for instance in the case of plosives, which are perceived in large part through characteristic effects on the formants of adjacent vowels. The place of articulation associated with a stop is generally less fixed than impressionistic data initially suggest, and may in fact vary, however slightly, as a function of the type of vowel following the stop. In other words, stops in a given language generally present different characteristic patterns of coarticulation vis-a-vis following vowels, patterns that are evident in the changes to the formant structure of following vowels.

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[1] This paper would of course not have been possible without the help of several Karitiâna friends, who offered to let me record them, and who were particularly gracious and welcoming to me.

One way to describe the characteristic patterns of coarticulation with following vowels, associated with particular stops, is via the implementation of locus equations. Locus equations were first described by Lindblom (1963, see also Linblom et al. 2007), and have been most extensively explored and detailed by Sussman (1994) and colleagues (Sussman, McCaffrey, and Matthews 1991; Sussman, Hoemeke, and McCaffreey 1992; Sussman, Hoemeke, and Ahmed 1993; Sussman and Shore 1996, *inter alia*).

As Fruchter and Sussman (1997:2997) note:

> 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.

In short, locus equations characterizing a particular consonant take the typical slope-intercept regression form of *y=mx+b*. Locus equations represent the F2 onset of a given vowel as a function of the F2 for the midpoint of a given vowel. That is, the F2 onset value associated with the release of a previous stop is seen to vary in accordance with the target F2 of the following vowel. For this reason, locus equations are useful in uncovering the extent to which the place of articulation (POA) of particular stops is influenced by the positioning of the tongue during the production of following vowels.

It has long been established that F2 onset values are strong predictors of place of articulation of consonants preceding the sampled vowel (cf. Liberman et al. 1954). Not surprisingly, then, the slope associated with a given locus equation varies in accordance with the degree of coarticulation associated with a particular preceding POA in a language's set of plosives. Flatter slopes tend to describe preceding stops with low degrees of coarticulation — that is, stops that are relatively resistant to changes in place of articulation, regardless of the location of a following vowel.[2] Flatter slopes (closer to 0.0) occur when F2 measurements at vowel onsets following a particular consonant are relatively fixed, and are not greatly influenced by the following target F2 values, i.e. the F2 values at a vowel's midpoint. Conversely, more positive locus equation slopes (closer to 1.0) are suggestive of high degrees of coarticulation between a stop described by a particular locus equation and the vowels following that stop.

As an example of previously described locus equations, consider that Sussman, McCaffrey, and Matthews (1991) found that the locus equation for the /b/ of their English-speaking subject could be described as *y=0.813x+231*. That is, the following onset F2 value could be generally predicted to be .813 times the value of the following vowel-midpoint F2 value, plus 231 Hz. (This correlation held at r^2=.959.) The locus equation describing

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[2] Unless otherwise noted, the term *coarticulation* or *CV coarticulation* is used here to refer to the degree to which a consonant changes its POA depending on the position of the following vowel. Of course vowels can also vary in terms of position depending on the POA of the preceding consonant. Such "vowel coarticulation" is discussed at a few points in this paper. However, in such cases the particular type of coarticulation being discussed is drawn out explicitly.

/d/ for the same speaker was *y=0.394x +1217* (r^2=.915). Interestingly, the /g/ was best described using two equations — one for front velars, *y=0.261x+1614* (r^2=.831), and one for back velars, *y=1.223x+169* (r^2=.749). (This bifurcation of the English velar POA has been verified in subsequent studies, and is discussed further in section 4.)

Locus equations have proven useful in the description of coarticulation in a number of languages including Swedish (Lindblom 1963), Canadian English (Neary and Shammass 1987), American English (Sussman, McCaffrey, and Matthews 1991), Thai, Cairene Arabic, Urdu (Sussman, Hoemeke, and Ahmed 1993), as well as others. In each case, the locus equations based on formant readings are consistent with the interpretation that the relationship of F2 onset and F2 vowel serves as an important cue to place of articulation. This is not to say that this relationship, in and of itself, can specify place of articulation (cf. Fowler 1994), as contrasts between locus equation data and EPG data suggest (Tabain 2000). Despite their limitations, however, locus equations are clearly useful in helping to uncover certain articulatory and perceptual correlates characterizing particular consonants. In a similar vein, Idsardi (1998:1) notes that while locus equations cannot "characterize final consonants or their relation to pre-vocalic consonants," they "are approximately abstract enough to define the upper limit on phonological distinctions for places of articulation."

Despite the demonstrated usefulness of locus equations in describing coarticulation effects, they have generally been ignored when it comes to field research. With the notable exception of Tabain and Butcher (1999), who employ locus equations in the description of stops in Yanyuwa and Yindjibarndi, the implementation of locus equations has generally been restricted to the description of widely-spoken languages, in laboratory settings. This quantitatively-oriented method was perhaps not generally available to field linguists before the advent of notebook computers with high processing rates. However, at present, the description of stops via locus equations is a relatively straightforward procedure, even for linguists in remote settings. For instance, as we see below for Karitiâna (K henceforth), each of the stops in the phonemic inventory has a predictable pattern of coarticulation, as evidenced by the locus-equation data. These patterns are generally quite subtle and do not surface in transcription-based data. The patterns allow for more complete descriptions of plosives at particular places of articulation. In the case of the K data, the three POA's considered can be categorized by disparate locus equations, each of which reveals information about the place at which the corresponding stop is articulated. In other words, by examining a particular locus equation in K one can tell whether the consonant characterized by that locus equation is bilabial, alveolar, or velar. More specifically, the data presented below (cf. §4.4) suggest that K velar stops can most accurately be considered back velars, rather than front velars. The greatest contribution of the locus equation data, however, is their role in revealing patterns of consonantal coarticulation, i.e., the ranges of variance of POA characterizing bilabial, alveolar, and velar plosives, respectively.

Given that coarticulation patterns serve as an important perceptual cue for stop POA, uncovering such patterns illustrates the efficacy of the given methodology in describing aspects of the sound systems of poorly-documented languages. Perhaps if future field-based studies include this simple quantitatively-oriented methodology, findings on other endangered languages may be contrasted with this one, in order to build a greater understanding of subtle patterns of CV coarticulation in such languages. Also, while more locus

equation data from a variety of languages could offer interested linguists valuable cross-linguistic data on coarticulation, they could also serve to better document phonetic patterns in particular under-documented languages. Another potential implementation would be pedagogical; for example, data could be re-interpreted for language learners to provide important information about the pronunciation of a set of consonants. As mentioned, the locus equation data for K suggest that the velar stop in that language is best described as a back velar stop. Similar findings in other languages could help language learners better articulate a set of plosives.

Finally, while locus equation analysis can be used to better document articulation, and is based on data from speech production, it helps to describe an important aspect of speech perception. As Sussman, Hoemeke, and Ahmed (1993:1256) note, the "most fundamental problem that has shaped both research and theory in speech perception for the past 50 years is the problem of contextual variability in relation to acoustic/phonetic invariance." Locus equations present an important avenue for understanding how speakers of a language like K perceptually discriminate between contextually variable stops, by perceiving patterns in the F2 values of vowels following such stops.

2. TUPÍ-KARITIÂNA. K is a Tupí language spoken in Rondônia, Brazil. As of 2006, there were approximately 260 K (Everett 2006:458), a substantial increase from the figure of 64 provided by Landin (1989), who collected her data in the mid 1970s.[3] However, despite the growth of the population in recent decades, the preservation of the K language faces several social obstacles, given the continued encroachment of the Brazilian population near the sole K reservation, and given the increased commerce between K and Portuguese speakers, which takes place solely in Portuguese. At this time most K, and all K young adults, speak Portuguese, though their first language is in most cases K.

K has received attention from several linguists in the preceding decades, beginning with Landin (1983), and continuing with the work of Storto (1999) and Everett (2006). Recent studies on the language (Demolin and Storto 2007, Everett 2007) have demonstrated typologically remarkable patterns of velic movement in the language. For example, Everett (2007) suggests that the temporally indeterminate nature of nasal gestures in the language contravenes expectations, based on cross-linguistic studies of nasality such as Beddor 2007. One of the effects of the indeterminacy described is the surfacing of a wide-variety of allophones of the bilabial, alveolar, and velar nasals in the language, especially in intervocalic positions. This fact is discussed further below, in the context of locus equations.

The consonant phonemes of K are presented in Table 1. This inventory is generally unremarkable and consistent with other Tupí languages[4] (Rodrigues 1999:113).

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[3] For a discussion of this rapid population growth, I refer the reader to Everett 2006:458-460.

[4] K is one of two languages in Tupí-Arikém, one of ten branches of Tupí. The other language in the branch, Arikém, is now extinct.

	BILABIAL	ALVEOLAR	POST- ALVEOLAR	VELAR	GLOTTAL
STOPS	p	t		k	
FLAPS		ɾ			
AFFRICATES			tʃ[5]		
FRICATIVES		s			h
RESONANTS	m	n		ŋ	
GLIDES	w				

TABLE 1: The Consonantal Phonemes of Karitiâna, in IPA[5]

SHORT		LONG		NASAL	
i		iː		ĩ	
	ɨ		ɨː		ɨ̃
e	o	eː	oː	ẽ	õ
	a		aː		ã

TABLE 2: The Vowels of Karitiâna, in IPA

As seen in table 2, the vowel inventory of K is also similar to other Tupí vowel systems, and to Amazonian vowel systems more generally. Vowels may be contrastively lengthened or nasalized. The functional load of vowel lengthening is relatively modest, however.

In figure 1, the vowel inventory of a 22-year-old male speaker (MS henceforth) is represented. This chart represents eight tokens of each of the five vowels, plotted according to F1-F2 vowel space. The tokens in figure 1 were normalized using the Lobanov (1971) normalization procedure.[6] Figure 1 is returned to in the discussion of coarticulation below, where those tokens highlighted with ellipses in the figure are discussed.

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[5] The phonemic status of the post-alveolar affricate is relatively unclear, given its complementary distribution with a post-alveolar nasal variant. Everett (2007) chooses to consider the nasal variant an allophone of the affricate, given that the nasal variant in question does not display the patterns of pre- and post-oralization characterizing the other K nasals. Storto (1999) and Everett (2006) posit a post-alveolar nasal phoneme, however, and the present study does not attempt to draw any further conclusions on the matter.

[6] The transcription of this vowel with the IPA ˆ symbol may seem odd given the relatively low height of the vowel, also evident in the F1 values presented in Figure 1. The ˆ symbol is used here since previous works on K employ this symbol. The current relatively low position of this vowel may be due to a change in progress. Cf. Everett 2006:74-92 for a discussion.
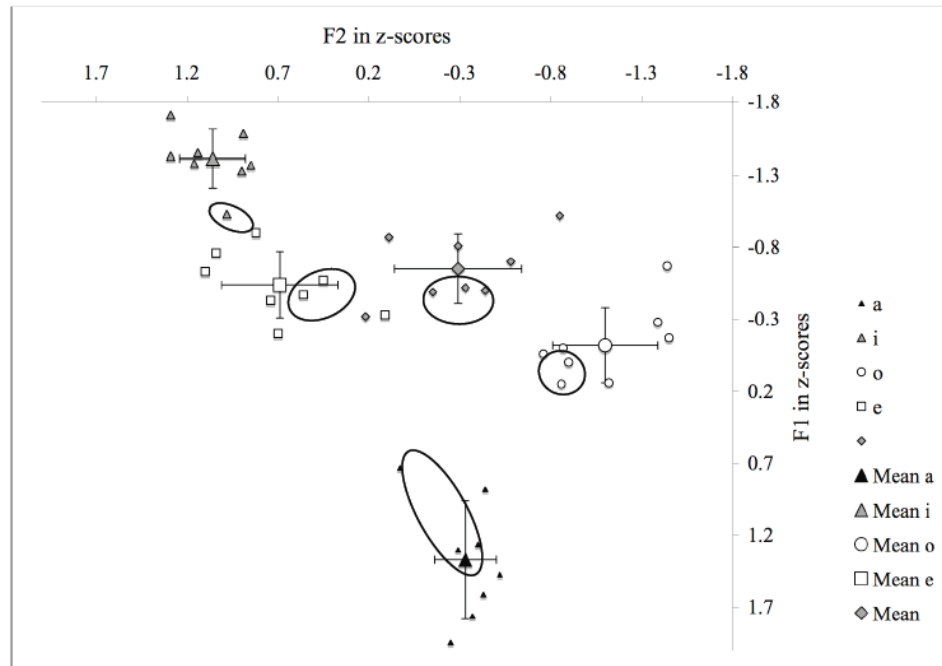
FIGURE 1: Sample plots of vowel tokens, with means and standard deviations, for MS. Ellipses circumscribe vowel tokens following /t/. Larger symbols represent vowel means.

3. METHODOLOGY. The present study is based on a series of digital recordings gathered in the state of Rondônia between 2005 and 2007. The recordings were collected in the city of Porto Velho, in an office where background noise could be monitored and controlled. The recordings were made directly onto a Mac G4 laptop, via a SONY FV-220 dynamic microphone, using Praat (Boersma and Weenink 2005) software while employing a sampling rate of 44.1 kHz.

The findings are based on hundreds of recordings of CV tokens, taken from words excised from carrier frames, or short clauses containing a word with a particular target vowel. The carrier frames were designed to account for factors such as location within a pitch contour, so that the formant readings were taken from words occurring clause-initially, clause-medially, and clause-finally. The stops considered for this study were taken from stressed syllables. Stress in K is instantiated primarily via increased loudness, as measured in sones (cf. Everett 2006).[7] In K, word-level stress generally occurs on the final syllable of a lexeme. There are exceptions to this pattern, however, including bisyllabic words in which the nuclei of both syllables have the same vowel quality. Most of the CV pairs considered for this study, however, occurred in the final or only syllable of a word. In

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[7] As Storto (1999) observes, pitch is also generally increased in the nuclei of stressed syllables. However, Everett (2006) suggests that pitch is a relatively weak correlate of word-level stress, when contrasted to loudness, which is due in part to the more positive spectral tilt of stressed vowels in the language.

polysyllabic words, the syllable preceding the CV pair tested typically consisted of another CV pair, since open syllables of this sort are unremarkable, both crosslinguistically and in K The vowel preceding the CV pair tested was controlled for, in that no vowel was allowed to occur at a significantly greater rate than any of the other five K vowels. Visual inspection of the many tokens in question suggested that preceding vowel type did not noticeably affect the locus equation values of subsequent CV pairs.

In general, the methodology adhered to the template for field-based acoustic research offered in Ladefoged 2003, and is consistent with that evident in other quantitatively-oriented phonetic studies of endangered languages, e.g., Gordon, Munro, and Ladefoged 2000 or Maddieson, Smith, and Bessell 2001. Examples 1–6 contain samples of the carrier frames employed. In each of the examples, one of the words is underlined. It is from such underlined words that the CV pairs were analyzed for F2 onset and F2 midpoint values. The carrier frames were chosen since other words could easily be swapped for the underlined words in question, allowing for formant analysis of different CV pairs embedded in the same portion of the intonation contour as previous CV pairs taken from the same carrier frame.

1. *pyty-pa*   *okyp*   *naka-a-syp*   *ahy-pa*[8]
   eat-NMLZ[9]   above/on   3ABS.AGR[10]-be-PROG:supine drink- NMLZ
   'The cup (drink thing) is above the table (eat thing).'

2. *deso*   *soka*-*pip*   *naka-a-syp*   *ep*
   mountain   side-ALL   3ABS.AGR -be-PROG:supine   tree
   'The tree is on the side of the mountain.'

3. *y-ota*   *na-oky-t*   *ombaky*
   1S.GEN-friend   3ABS.AGR-kill-NFUT   jaguar
   'My friend killed the jaguar.'

4. *ombaky*   *na-oky-t*   *pat*
   jaguar   3ABS.AGR-kill-NFUT   macaw
   'The jaguar killed the macaw.'

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[8] These clauses are transcribed using the K orthography. *y* represents the high central vowel.

[9] Leipzig glossing rules are employed, with the exception of NFUT, referring to the nonfuture tense. The Leipzig glossing rules are a set of conventions for interlinear glosses developed at the University of Leipzig and the Max Planck Institute. (http://www.ru.nl/dbd/LGR04.09.21.pdf)

[10] The *na(ka)-* morpheme is typically utilized when the absolutive nominal in a declarative clause is a 3rd person referent. However, there are exceptions to this pattern noted in Everett 2006, and a different gloss is suggested in that work. Since the function of the morpheme is not relevant to this discussion, I adopt the more transparent gloss evident here.

5. *yn*   *na-aka-t*   *i-soot*   *sarait*   *epesap*   <u>*ket*</u>
   1S   3ABS.AGR-COP-NFUT   INTR-see   ugly   leaf   green
          'I don't like the money.'

    The locus equation data were based on recordings from four native K speakers, two males and two females. Several other K speakers were also recorded. Initial analyses of these recordings suggest a general consistency of locus equation patterns across all recorded speakers. The locus equation data for the four speakers considered here are presented in tables 5 and 6 in sections 4.2 and 4.3, respectively.

    As can be seen in table 1, there are only three stops, all voiceless, in K Locus equations are most effective when applied to stops, since during any given articulation of a stop-vowel sequence, the tongue must transition from a fixed point of articulation where occlusion occurs, to the position needed for the following vowel. This movement results in transitional values for the following vowel's F2, as the tongue continues to shift position from the onset to the nucleus of the following vowel. Since fricatives and approximants do not require occlusion at one particular point in the oral cavity, they are not as easily characterized by F2 transition patterns. Nasals are also not easily categorized by locus equations, due to the effects of velic lowering on vowel formant levels. Given that locus equations are most effective when applied to stops, the articulations of K. /p/, /t/, and /k/ were logical focal points for this study. However, the bilabial, alveolar, and velar nasal consonants in K are very frequently post-stopped, and even surface without any nasality in some cases, in intervocalic position and word-initial position. Given the frequently stop-like nature of these sounds, locus equations were also ascertained for each of the post-stopped allophones of the three nasal consonants. This allowed for the contrast between locus equations for voiced "stops" and those characterizing voiceless stops at the same place of articulation.

    In order to arrive at the locus equations, F2 measurements were taken at two separate points in a given CV pair. One of these points was approximately 0–20 ms after the beginning of the vowel onset, when a clear F2 reading was available. This reading was taken subsequent to the consonantal burst, in a manner consistent with previous locus-equation studies on voiceless stops, e.g. Yeou (1997), and differing slightly from studies in which the F2-onset measurements are taken at the first glottal pulse following a voiced consonant, e.g., Sussman and Shore (1996). (The effects of these slightly differing methods are considered in the discussion of the results obtained.) As in previous studies, the second F2 measurement was taken during a stable portion of the vowel's midpoint, typically 60–100 ms after the point at which the first measurement was taken.

    F2 values were measured using a Linear Predictive Coding (LPC) analysis calculated over a 10-ms segment of the vowel in question. The formant values gathered were checked by visually examining wide-band spectrograms based on Fast Fourier Theorem (FFT) analysis, in order to better insure their reliability. In figure 2 a sample FFT-based spectrogram is presented, along with LPC-based formant tracks superimposed. The vertical lines highlight the portions of the stressed vowel during which the F2 values were analyzed.

    In order to derive the locus equations for the stops in question, 4–6 separate tokens of each of the K vowels were sampled following each particular consonant. This was done

for each speaker, by considering different words in which the relevant CV pair occurred. So, for instance, in the case of the /p/-/a/ pair, the token in figure 2 was analyzed, as well as five other tokens of /p/-/a/ taken from different words produced by MS. In this way, approximately 75 total tokens were considered for /p/, /t/, and /k/, for MS, as well as for each of the remaining speakers. Another 75 total tokens were considered for [b], [d], and [g], for each of the speakers. Put simply, the results of this study are based on a few hundred CV pair analyses such as that depicted in figure 2. Locus equation analysis does not require thousands of tokens, and such analysis is straightforward once the acoustic data are collected and a method for sampling the data is selected.
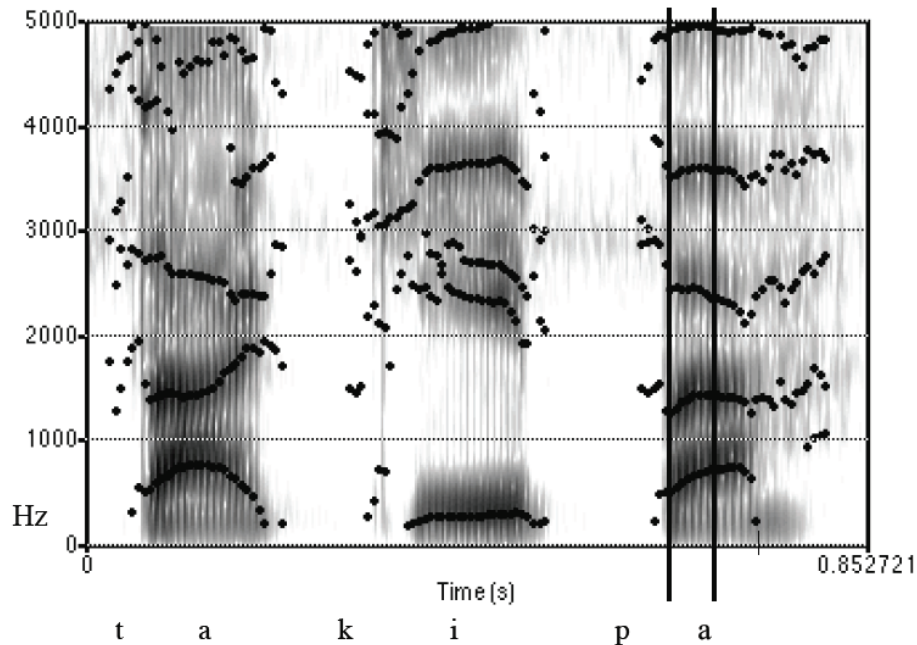

FIGURE 2: Spectrogram and formant tracks for *takipa* 'rope' (MS).

4. DATA.

4.1 FURTHER BACKGROUND. Before considering the locus equation data from K, it is worth considering similar data from a previous study in order to illustrate the manner in which such data might be interpreted. As mentioned above, previous studies have suggested that higher locus equation slopes, near 1.0, are suggestive of greater CV coarticulation. The motivation for this correlation between steepness and coarticulation is simply that steeper locus equation slopes suggest greater similarity between F2 onset values and F2 midpoint values. As an extreme scenario, consider that if the F2 onset and F2 midpoint values were identical in all cases for the vowels following a given stop, the slope of the locus equation would be 1.0 and the y-intercept would be zero. While such a scenario is not plausible in actual speech, what we find is that in some cases the locus equation characterizing a par-

ticular stop has a slope approximating 1.0. As we see in various subsequent tables, when locus equations are characterized by high slopes they are also characterized by relatively low y-intercept values.[11] High slopes characterize stops with high degrees of coarticulation because the F2 onset and F2 vowel values following such stops are quite similar, and because this similarity implies proximity of tongue position at vowel onset with tongue position at the vowel midpoint. Conversely, if the locus equation characterizing a given stop is not steep, this implies a greater difference between F2 onset values and F2 midpoint values. Such a difference is in turn suggestive of a less malleable place of articulation for the stop, vis-à-vis following vowels (cf. Cole, Choi, and Kim 2002:3).

Given the expected correlations between slope values and degrees of coarticulation, we are able to interpret locus equation values such as those provided above for English /b/, /d/, and /g/. As first noted by Sussman, McCaffrey, and Matthews (1991), the locus equation data for /d/ is suggestive of relatively little coarticulation, given its low slope of .394. The locus equation for the back velar found in Sussman, McCaffrey, and Matthews 1991 has a slope of 1.223, suggesting much greater coarticulation. Similarly, the locus equation of /b/ is much closer to 1.0 than that of /d/, again suggesting greater coarticulation. The greater coarticulation figures associated with bilabials are obviously motivated by different factors than those of back velars, however. A labial consonant has less influence on the lingual production of the following vowel, since the tongue does not have to move from a previous fixed position as in the case of alveolar or velar stops. In such cases, then, coarticulation refers to the fact that the tongue can position itself for a particular vowel during the production of a preceding bilabial. In that sense, the nature of bilabial-V coarticulation differs from that of alveolar-V coarticulation, and also from that of velar-V coarticulation. The high slope (and greater coarticulation) characterizing velar locus equations is generally due to the fact that the tongue anticipates the position of the following vowel during the production of the velar stop, so that the point of articulation of the velar consonant varies somewhat in accordance with the position of the following vowel. Of course the high slope characterizing bilabial locus equations does not imply a similar change at the point of articulation during the production of the consonant.

The coarticulation patterns associated with these three places of articulation have been replicated in studies on English (e.g., Cole, Choi, and Kim 2002), as well as other languages (e.g., Sussman, Hoemeke, and Ahmed 1993). Interestingly, we will see shortly that the same pattern generally holds for K. However, the locus equation data presented reveal important language-specific patterns of CV coarticulation.

As can be seen in table 1, there are only three oral stops in K, all of which are voiceless. Table 3 contains a list of a few minimal or near-minimal pairs illustrating the phonemic

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[11] As one reviewer correctly points out, if the slope of a locus equation were near 1.0 but the y-intercept were high, the equation would *not* be suggestive of high degrees of coarticulation. However, from an articulatory standpoint such a scenario is implausible. For example, a locus equation of 1.0x + 1000 would imply that, no matter what vowel followed a given consonant, its F2 value would be expected to increase 1000 Hz from onset to nucleus. In other words, the type of vowel would be completely changed every time it followed a particular consonant. Such a locus equation would imply that even vowels with inherently high F2 values, e.g. /i/, would see their F2 increased substantially. Such an increase is impossible, given that such vowels are already located at the front of the vowel space.

status of these stops. In the literature, locus equation analysis is most frequently applied to voiced stops. This is because F2 onset measurements can be taken closer to the actual preceding consonant, for vowels following voiced consonants. The greater burst and greater duration of VOT associated with voiceless stops precludes the collection of reliable F2 values immediately following such sounds. Therefore, the transition of F2 values from F2 onset to F2 nucleus is often (but not always) more noticeable for vowels following voiced rather than voiceless consonants, since the values can be collected further apart, allowing for greater transition between them. As a result the slopes for locus equations characterizing voiced stops may be less steep than the slopes of those characterizing homorganic voiceless stops.[12] In addition, other differences between locus equations for voiceless and voiced stops could potentially surface in a given language. For that reason, I also present locus equation data for [b], [d], and [g] in K As mentioned above, these oral stops surface as variants of their homorganic nasal phonemes depicted in table 1, when adjacent to stressed oral vowels.

/põɲ/	[põɲ]	'left side'	/kõɲ/	[kõɲ]	'stomach'
/keɾep/	[keɾep]	'grow'	/teɾep/	[teɾep]	'straight,honest'
/otɨt/	[otɨt]	'return'	/otɨ/	[otɨ]	'bathe'
/mɨ/	[bɨ]	'let's go'	/mɨt/	[mbɨt]	'pan'
/ŋop/	[ŋgop]	'wasp'	/ŋok/	[ŋgok]	'manioc'
/otɨ/	[otɨ]	'moon'	/opi/	[opi]	'ear ring'

TABLE 3: Sample of Minimal or Near-minimal Pairs, for K /p/, /t/, and /k/

As we will see, the locus equation data for oralized allophones of nasal phonemes, as in the words in table 4, are consistent with the locus equation data based on /p/, /t/, and /k/. In the following sections I focus first on locus equation data for the phonemic voiceless stops, before considering supporting data based upon allophonic voiced stops.

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[12] This does not always prove to be the case for the K presented here, since the distance between F2 onset and F2 midpoint measurements was kept fairly constant for all the CV sequences analyzed.

WORD	SAMPLE TOKENS
'wide'	pe.ˈdn̩dot , pẽ.ˈndot , pe.ˈdot
'house'	a.ˈbm̩bi , ã.ˈmbi , a.ˈbi
'vomit'	e.ˈgŋ̩gɨ, e.ˈŋgɨ , e.ˈŋgɨ
'speak'	ˈhadn̩ã , ˈhadna

TABLE 4: Examples of Word-medial 'Stopped' Nasals, in IPA[13]

4.2. K LOCUS EQUATIONS. In table 5, the locus equations for each of the K voiceless stops are described, for four different speakers. As we see in table 5, there is remarkable consistency between the locus equations of these four speakers. In the case of each speaker, the locus equation slopes are greatest for /k/, followed by /p/, with the lowest slope characterizing /t/. The y-intercept is generally greatest for /t/, followed by /k/, with the lowest intercept characterizing /p/.[14] The consistency of these patterns is much clearer when the equations are depicted graphically, as is done in the following section. For the sake of space, however, only the locus equations of two speakers, the 22-year-old male (MS) and the 25-year-old female (FS), are presented graphically in 4.3.

PHONEME	22-YEAR-OLD MALE			25-YEAR-OLD FEMALE		
	SLOPE	Y-INT	r^2	SLOPE	Y-INT	r^2
p	.94	-39	.98	.95	-84	.96
t	.66	499	.91	.67	527	.92
k	.94	253	.96	1.03	25	.96

TABLE 5: Locus Equations for Voiceless Stops of Four Karitiâna Speakers

4.3 GRAPHS OF K LOCUS EQUATIONS. In figures 3 and 4 the locus equations for /p/, for MS and FS, respectively, are presented. As these figures demonstrate, there is a high degree of correlation between the F2 onset and F2 vowel midpoint values for K /p/. This correlation is evidenced by the fact that the slopes of the locus equations approach 1.0, and that that the y-intercept values of the equations are close to zero. Given the lack of change between onset and vowel midpoint F2 readings, we can state that there is a high degree of

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[13] For discussions of this allophony, I refer the reader to Storto 1999 and Everett 2006.

[14] For the 28-year-old female, the y-intercept for /p/ is greater than that for /k/, but only marginally so.

coarticulation, in the sense that the position of the tongue during the production of the labial consonant appears to be similar to that of the position of the tongue during the production of the following vowel. As mentioned above, this is a different sort of coarticulation than that evidenced by, e.g., K /k/ (described below), since the primary articulator in the case of /p/ does not shift closer to the tongue's position for the following vowel.
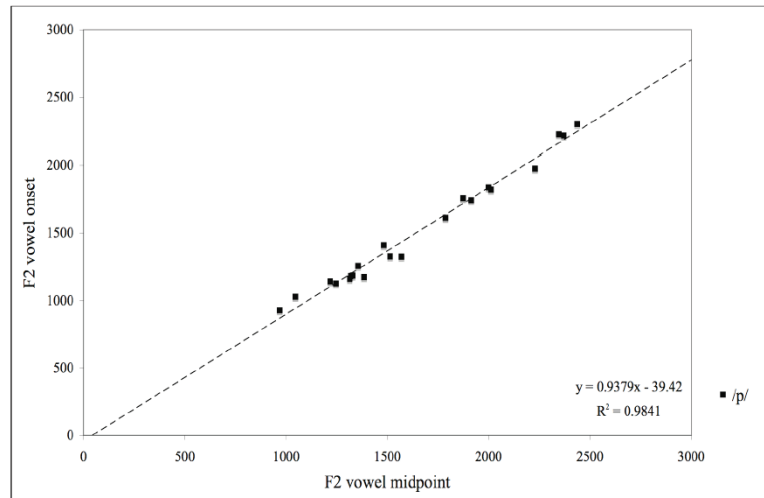

FIGURE 3: Locus equation, with plotted tokens and regression line, for MS's /p/.
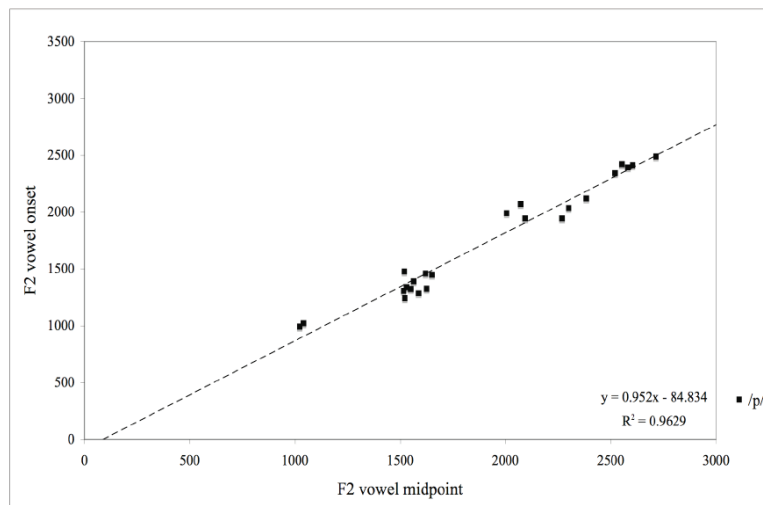
FIGURE 4: Locus equation, with plotted tokens and regression line, for FS's /p/.

Another distinguishing characteristic of the /p/ locus equations is the negative y-intercept of the linear regression. As seen in figures 3 and 4, the y-intercept values for /p/ are negative. Combined with the fact that the slope of the equation is less than 1.0, these negative intercept values imply that the F2 onset values are generally lower than the corresponding F2 midpoint values. While locus equations for bilabial consonants tend to have relatively low y-intercept values crosslinguistically (cf. Sussman, Hoemeke, and Ahmed 1993:1263), these values are not generally negative as we see here. That F2 onset values are generally less than F2 vowel midpoint values, for vowels following /p/ in K, suggests that there is a fair amount of residual labialization during the production of such vowels. The lower F2 onset values are due to slight labialization, which increases the size of the oral chamber in vowel onsets and therefore lowers F2 onset values.

Figures 3 and 4 suggest two forms of coarticulation, then. One of these is lingual, i.e. the tongue anticipates the height and backness of the following vowel during the production of the preceding /p/. The other is labial and could be characterized as carryover rather than anticipatory. Labialization carries over to the onset of the production of the following vowel, so that onset F2 values are consistently lower than vowel-midpoint F2 values.

Locus equations such as those evident in figures 3 and 4 help us to better understand the articulatory correlates of K /p/. The same is true for the voiceless alveolar stop in the language. In figures 5 and 6 the locus equations based on the same two speakers' tokens of /t/ are presented. The plots and regressions evident in these figures allow us to draw several conclusions. The most obvious conclusion is that there is less coarticulation in the case of /t/ than there is in the case of /p/ (or than /k/, as we will see below).
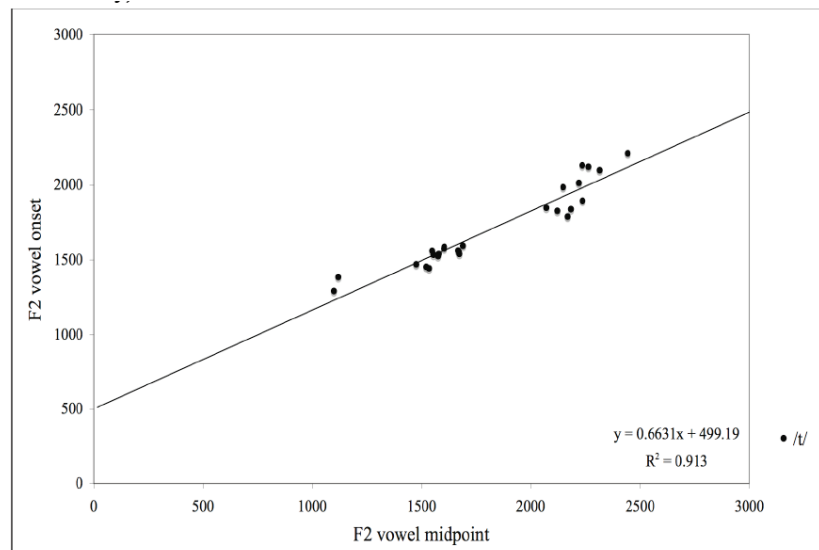

$y = 0.6631x + 499.19$
$R^2 = 0.913$
● /t/

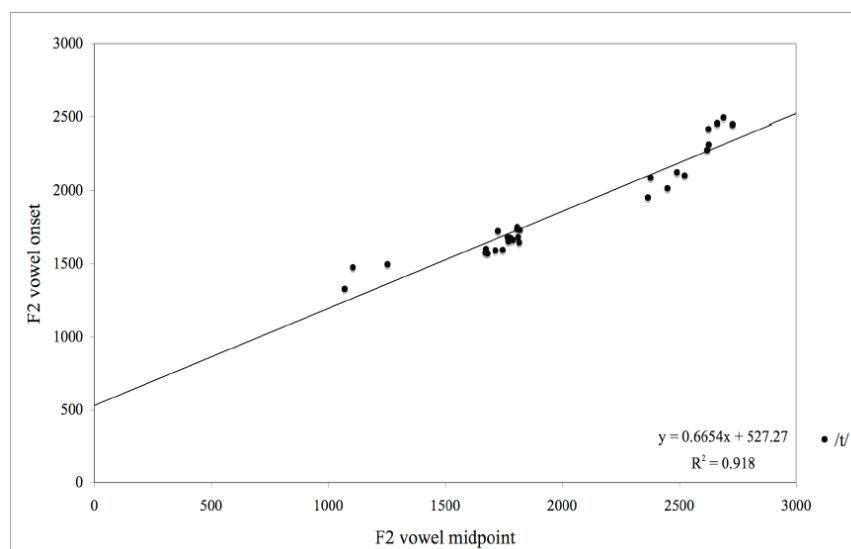FIGURE 5: Locus equation, with plotted tokens and regression line, for MS's /t/.

FIGURE 6: Locus equation, with plotted tokens and regression line, for FS's /t/.

The lessened coarticulation associated with /t/ is evidenced by the higher y-intercept values and less steep slope. Both of these factors suggest a greater disparity between F2 onset and F2 midpoint values than was observed for /p/. In other words, the F2 onset value reflects the constriction of the oral cavity during the production of the alveolar consonant. The change in F2 values from vowel onset to vowel midpoint reflects the tongue's movement from an alveolar POA to the position associated with the following vowel. If the slope of the regression lines in figures 5 and 6 were closer to 1.0, and if the y-intercepts were closer to zero, there would be greater evidence for CV coarticulation.

One of the crucial observations to be made by contrasting figures 5 and 6 is that, like figures 3 and 4 (and the data for all four speakers in Table 5), they reflect a remarkable consistency across K speakers. Also, the data show that this consistency of coarticulation patterns cannot be ascribed to overall patterns of similarity in F2 values. As a careful examination of figures 3–6 (as well as 7 and 8 below), demonstrate, there are significant inter-speaker disparities in the actual F2 values in question. This is not surprising given that one speaker is male and the other female. Since females typically have shorter vocal tracts, the greater F2 values for FS are to be expected. Despite these greater F2 values, however, the locus equations for the two speakers in question are remarkably similar.

Before turning to a discussion of the locus equations for /k/, a final crucial observation regarding the /t/ locus equations is warranted. Figures 5 and 6 reveal that /t/ affects the F2 onset values of following vowels in different ways, according to the vowel's type. For example, consider the tokens of the /a/ vowel, which have low F2 values and so occur at the left-most part of the regression lines in figures 5 and 6. In the case of these tokens, the F2 onset value is generally greater than the F2 vowel midpoint value. This is consistent with the smaller oral constriction size associated with preceding /t/ consonants. The same relationship does not hold for tokens of the /i/ vowel, which have extremely high F2 values

and so occur at the right-most part of the regression lines in figures 5 and 6. Inspection of the figures reveals that for these tokens, the F2 onset value is generally *less* than the F2 vowel midpoint value. In other words, the plotted F2 data in figures 5 and 6 point to a particular F2 locus of origin associated with /t/. This abstract locus of origin likely serves as an important perceptual cue to place of articulation for K speakers, as similar loci have been shown to serve in other languages (cf. Fruchter and Sussman 1997).

The locus equation data suggest that /t/ exhibits little coarticulation vis-à-vis following vowels, and that it affects the F2 onset values of those vowels. Interestingly, /t/ does not merely affect the F2 onset values of adjacent vowels. In fact, the F2 midpoint values are also affected. In general, vowels following alveolar consonants are produced in a relatively centralized portion of the F2-F1 plane. This centralization, while not pronounced, is apparent when the F2 vowel midpoint values in figures 5 and 6 are contrasted with those in figures 3 and 4, as well as those in figures 7 and 8 below. It is also readily apparent in the normalized vowel space for MS represented in figure 1. In that figure, the vowel midpoints of eight tokens of each of the five K vowels are plotted according to normalized values (z-scores). Nine of the ten tokens representing vowels following /t/ are highlighted via ellipses. Examination of the highlighted vowels reveals an interesting pattern. In each of the nine highlighted cases, the vowel in question is located in a more centralized portion of the normalized vowel space, when contrasted to the mean of the vowel type. In other words, the position of tokens following /t/ is noticeably affected by the preceding /t/. The tokens are located closer to the centralized abstract locus associated with /t/'s POA, as evidenced by the data for MS in figure 5. Put simply, the normalized vowel data support the conclusions drawn from the locus equation data. As in the case of /p/, then, the /t/ locus equations have revealed aspects of CV interaction that would not have been clearly discernible otherwise. In this case, the data suggest that the position of /t/ is not clearly affected by the position of following vowels. That is, there is no clear evidence for anticipatory coarticulation, at least not to the degree observed for /k/, which will be considered next. Instead, the data show that it is the vowels following /t/ that are slightly altered by the preceding POA. The F2 values of vowels following /p/ were also demonstrated to be affected by preceding /p/, however in that case the effect witnessed is a lowering of F2 due to labialization, rather than an altering of tongue position as in the case of vowels following /t/.

Having described the locus equation data for /p/ and /t/, I turn now to those associated with the speakers' productions of /k/-V pairs. As is apparent in table 5 as well as figures 7 and 8, the locus equations characterizing /k/ for all speakers are similar in that they display slope values near 1.0, suggesting high degrees of CV coarticulation. However, despite the high slope values, the correlation between F2 onset and F2 vowel readings for MS is not complete, since the y-intercept value characterizing the /k/ locus equation of this speaker is over 250 Hz. For most of the vowel tokens in figure 7, the F2 onset value is greater than the F2 vowel midpoint value. This suggests a high abstract locus for the /k/ consonant. This high locus results in higher vowel F2 onset values, when contrasted to F2 vowel midpoint values. However, this pattern is much less marked than the pattern of /t/ influence on the formants of following vowels. Even more significantly, the pattern is not evident in the /k/ locus equations for the remaining speakers, as the data for FS in figure 8 suggest.
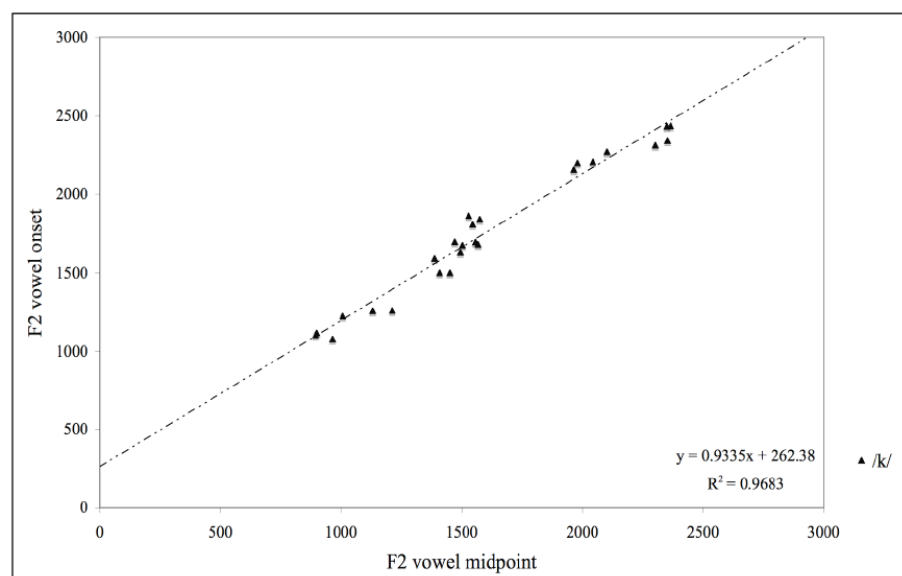
FIGURE 7. Locus equation, with plotted tokens and regression line, for MS's /k/.
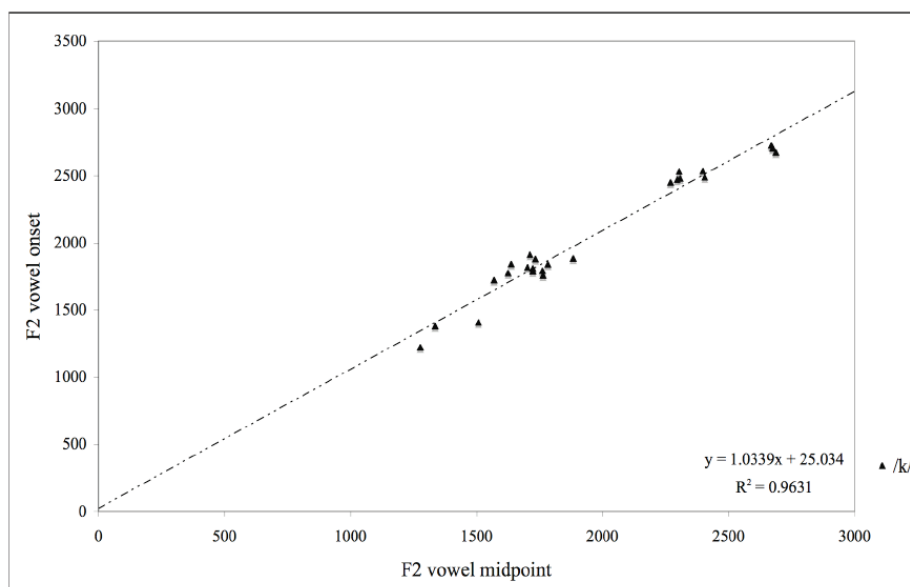

FIGURE 8. Locus equation, with plotted tokens and regression line, for FS's /k/.

While the regression lines evident in figures 7 and 8 are generally quite similar, then, they also reveal inter-speaker differences in patterns of coarticulation. Specifically, /k/ influences following vowel positions for MS in a manner not evident in the speech of the other subjects. The discovery of such subtle inter-speaker differences through locus equations highlights another potential use for implementing them in linguistic field work.

Despite the difference just mentioned, however, the locus equations for all four speakers reveal remarkably similar patterns of CV coarticulation. For MS and FS, these similar patterns are particularly evident if figures 9 and 10 are contrasted. These figures serve as a graphic summaries of important articulatory and perceptual correlates of consonant-vowel interaction in K, and reveal near-isomorphism between the production patterns of MS and FS, for the K stops. To my knowledge, no similar locus equation "summaries" exist in the literature for under-described or endangered languages. If such summaries were available, they could be easily compared to the findings in figures 9 and 10, and patterns of CV coarticulation could be contrasted across languages. Given that all Tupí languages have phonemic /p/, /t/, and /k/ (Rodrigues 1999:113), perhaps future field work will allow for the intra-Tupí contrast of such coarticulation patterns. For now we are left to observe the isomorphism of locus equation patterns across the two K speakers described by figures 9 and 10, as well as the remaining two speakers represented in table 5, who also present remarkably similar overall locus equation patterns for the sounds in question.
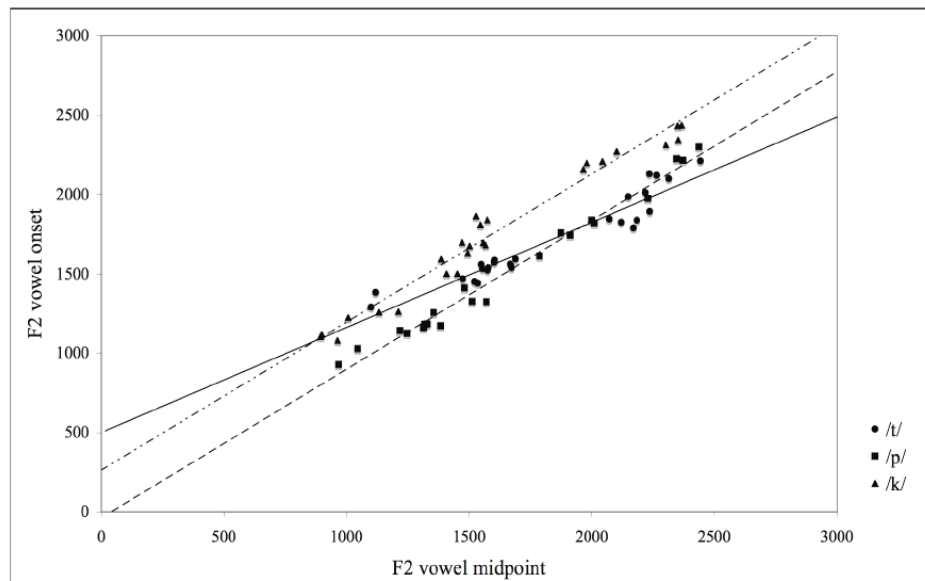

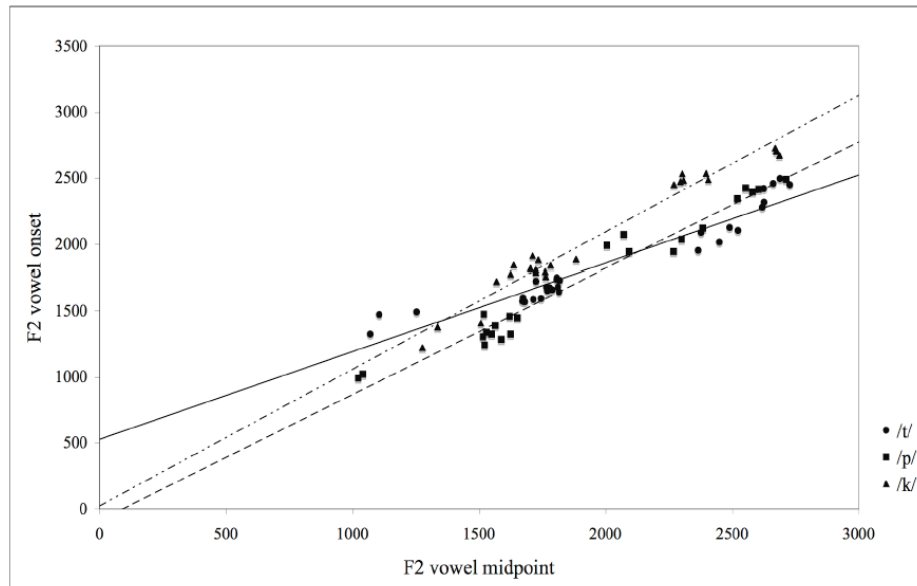FIGURE 9: Graphic summary of locus equations for MS's /p/, /t/, and /k/.

FIGURE 10: Graphic summary of locus equations for FS's /p/, /t/, and /k/.

One final bit of locus equation data merits inclusion in this discussion. This relates to the locus equations for voiced stops in K Inclusion of such data is important for two reasons. First, segments of voiced oral occlusion, while not phonemic in K, frequently surface as variants of the /m/, /n/, and /ŋ/, particularly in word-medial environments in words such as those in table 4. In many cases these segments exhibit no velic lowering whatsoever, and Everett (2006) suggest that the voiced stopped variants of the nasals in question have near-phonemic status. Regardless, the presence of such voiced stops in surface forms allows for the contrast of their locus equations with the phonemic voiceless stops in the language. The second reason that the locus equation data from these nasal allophones is worth mentioning is that most locus equation studies to date have focused on voiced stops. As mentioned above, the motivation for this is that voiced stops have shorter VOT's, and frequently allow for a greater distance between the F2 onset and F2 vowel measurements.

In figure 11, locus equation data for [b], [d], and [g] are depicted graphically. Figure 11 contains only data for MS; however the locus equation data for the remaining three speakers' productions of [b], [d], and [g] are presented in table 6. As an examination of the data in that table suggests, there is a high degree of inter-speaker consistency with respect to the voiced-stop locus equation data. To save space, I will focus on the relevant data for MS. As the data for MS in figure 11 suggest, the coarticulation patterns associated with /p/, /t/, and /k/ are also evident in their homorganic non-phonemic voiced counterparts [b], [d], and [g]. As a comparison between figure 11 and figure 9 demonstrates, there is a remarkable within-POA consistency of locus equation patterns, regardless of voicing status, for MS. In fact, the only clear differences between the locus equations for voiced stops, when contrasted with those for homorganic voiceless stops, are restricted to the /p/-

[b] pair. Examination of the locus equations on which figure 11 is based (evident in table 6) support this observation. When contrasted with the locus equation for MS's /p/, the locus equation for MS's [b] has a lower r^2 value (0.78 vs. 0.92) and a higher y-intercept value (684 Hz vs. 527 Hz). These relatively small differences may also be due to the greater gap in the time at which F2-onset and F2-vowel measurements are taken, for vowels following voiced stops. In general, then, the data for voiced stops in figure 11 support the conclusions on coarticulation patterns in K suggested by the locus equations for voiceless stops.
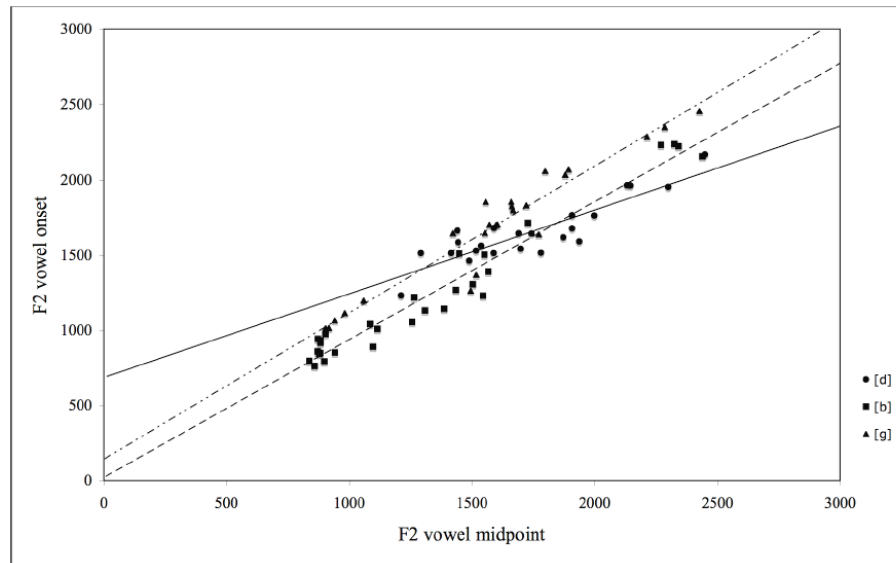

FIGURE 11: Locus equations for [d], [b], and [g], for MS. Note similarity with figure 9.

Table 6 presents the locus equation data for [b], [d], and [g], for each of the speakers represented in table 5 above. As a comparison between the two tables suggests, there is a remarkable within-POA consistency of locus equation patterns for all four speakers, for both voiceless and voiced stops. As in the case of the locus equations presented in table 5, recurrent patterns surface in the locus equation data in table 6. With respect to slope, the velar stop has the greatest slope for each of the four speakers, followed by the bilabial stop. The alveolar stop has the lowest slope, and differs markedly from the other two stop types. Again, this is suggestive of less overall coarticulation for alveolar-V sequences, when contrasted to bilabial-V sequences and velar-V sequences. The data in table 6 reveal as well that the locus equations for alveolar stops once again present greater y-intercepts, when contrasted to the y-intercepts characterizing bilabial and velar stops. In other words, the data for [b], [d], and [g] are generally quite consistent with the data for /p/, /t/, and /k/, for each of the four speakers considered.

LANGUAGE	SEGMENT	LOCUS EQUATIONS	
		SLOPE	Y-INT
Thai	*d*	0.30	1425
English	*d*	0.43	1073
Swedish	*d*	0.32	1096
Arabic	*d*	0.25	1307
Urdu	*d*	0.50	857
Karitiâna (MS)	*t*	0.66	499
	d	0.56	684

TABLE 6: Locus Equations for Voiced Stops of Four Karitiâna Speakers

4.4 CONTRASTS WITH PREVIOUS STUDIES. The findings presented so far are in several respects consistent with locus equation data based on unrelated languages such as Thai, English, Swedish, Arabic, and Urdu. As the data for these languages in Sussman, Hoemeke, and Ahmed 1993 suggest, the locus equations associated with alveolar stops tend to have less steep slopes, when contrasted with those associated with bilabial and velar stops. This pattern is also corroborated by the data in Tabain and Butcher 1999 for Yanyuwa and Yindjibarndi. In other words, there is a crosslinguistic tendency for alveolar stops to exhibit less coarticulation, vis-à-vis following vowels, when contrasted with bilabial and velar stops, and this tendency surfaces in K. However, it is important to note that while alveolar stops in K exhibit less coarticulation, when contrasted to the other POA's in K, they appear to exhibit generally *greater* coarticulation, when contrasted to the alveolar stops in the aforementioned languages. This is evident from the slope differences of the locus equations in table 7, which contains data from Sussman, Hoemeke, and Ahmed 1993, as well as Tabain and Butcher 1999. The table also contains locus equation data for the four K speakers, in the form of ranges of slope and y-intercept values. These ranges are based on tables 5 and 6. Note that the slope values for K [d] are greater than the slope values for /d/ in the other languages. Despite the relatively greater levels of alveolar coarticulation in K, however, it is worth noting the apparent similarity between K and Urdu, for the relevant locus equation data in table 7. The slope and y-intercept values for voiced alveolar stops are of the same order, suggesting perhaps similar POA's and similar patterns of coarticulation. The slope and intercept values for K /t/ approximate those for /t/ in Yanyuwa. [15]

[15] Given that quality locus equation data are available for only a small number of languages, it is difficult at present to judge the significance of this sort of similarity of locus equation values. However, if more data such as these were available, from a wide variety of languages, we would be better able to contrast locus equation findings, and perhaps establish a method for judging similarity or difference between locus equation patterns across speakers and languages. For now we are able to draw attention to the gross similarity of

LANGUAGE	SEGMENT	LOCUS EQUATIONS	
		SLOPE	Y-INT
Thai	*d*	0.30	1425
English	*d*	0.43	1073
Swedish	*d*	0.32	1096
Arabic	*d*	0.25	1307
Urdu	*d*	0.50	857
Karitiâna (MS)	*t*	0.66	499
	d	0.56	684

TABLE 7: Locus equations for alveolar stops in K and seven other languages

The locus equation slopes for /b/ in Sussman, Hoemeke, and Ahmed 1993 range from 0.70 to 0.81. The locus equation slopes for /p/ in Tabain and Butcher 1999 range from 0.80 (Yanyuwa) to 0.83 (Yindjibarndi). The slopes for [b] in K, as seen in table 6, are generally similar to these values, ranging from 0.84 to 0.93. The slopes for /p/, evident in table 5, are somewhat higher, with one as high as 1.01. Such high slopes could be due in part to the aforementioned differences between locus equations for voiced and voiceless stops.

LANGUAGE	SEGMENT	LOCUS EQUATIONS	
		SLOPE	Y-INT
Swedish	*g*	0.95	360
Arabic	*g*	0.92	229
Urdu	*g*	0.97	212
Yanyuwa	*k*	1.03	-125
Yindjibarndi	*k*	1.11	-213
Karitiâna (MS)	*k*	0.95-1.05	-70-253
	g	0.92-1.13	-122-141

TABLE 8: Locus equations for velar stops in K and five other languages

such patterns in some cases, and the gross dissimilarity in others. For instance, it is fairly clear from table 7 that the coarticulation patterns of alveolar stops in K are quite different from those exhibited in Thai, English, Swedish, and Arabic.

The locus equation slopes for K /k/ and [g] are extremely consistent with locus equations for velar stops in the literature, as evident in Table 8, which again contains data from Sussman, Hoemeke, and Ahmed 1993, as well as Tabain and Butcher 1999. It also contains data for the four K speakers, based on tables 5 and 6. The data in table 8 suggest that coarticulation rates between velar stops and following vowels are generally high crosslinguistically, and that K is unremarkable in this respect.

More data from the literature on velar locus equations can be brought to bear in our analysis of velar stops in K, however. Cole, Choi, and Kim (2002) present data suggesting that velar stops in English are actually best described by two locus equations, one for a front velar and the other for a back velar. The locus equations they present for the two separate English velars are found in table 9, along with locus equation values for K velars. The values in the latter case represent the means for all four speakers.

SOUND TYPE	LOCUS EQUATIONS	
	SLOPE	Y-INT
English front velars	0.48	1381
English back velars	1.03	72
Karitiâna (MS) *k*	1.03	25
Karitiâna (MS) *g*	0.97	141

TABLE 9. Locus equations for velar stops in K and English

Interestingly, the slopes for the English back velar and K /k/ are quite similar, and their y-intercepts are also quite similar. Such similarity of locus equations is suggestive of similar patterns of coarticulation, as well as an almost identical POA. It is interesting to note that in K, as in Swedish, Arabic, and Urdu, the velar stops cannot be divided further into two separate POA's, based on the locus equation data. Instead, the locus equation data suggest quite clearly that velar stops in K are characterized by one POA, which might be described as back velar. As was alluded to in the introduction, such a finding could be used to provide non-native K speakers an insight into the articulation of the language, one that might be hard to glean otherwise.[16] Perhaps if locus equation analysis were applied to more under-documented languages, similar fine-grained clarifications of POA could assist

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[16] I should note that, before examining these locus equation data, I had not realized that the velar stops in K were best considered back velars. After considering these data, I have become more perceptually aware of the articulation point of velar stops, both the backness of this articulation and the malleability of its placement. Such fine-grained distinctions are not always easy to transcribe of course, as evidenced by the fact that they have not been previously made by me, nor any previous linguists working on K.

linguists and language learners more generally as they strive to more carefully articulate the sounds in a given language.

5. DISCUSSION AND CONCLUSION. The results discussed have two primary types of applications. One of these is language-specific, as they serve to document an aspect of the sound system of an endangered Amazonian language. The other pertains to linguistic fieldwork methodology, as they have served to demonstrate how locus equation data can be gathered in the field, in order to more completely document the acoustic and articulatory correlates of plosives in a given language.

With respect to the language-specific findings, we have shown that in K the three voiceless stops, as well as the voiced-stop allophones of the nasals, display a relatively high degree of coarticulation vis-à-vis following vowels. This is especially true in the case of velar stops, which are similar to back velars in English in terms of coarticulation levels and likely in terms of POA. The locus equation data for labial stops in K have shown that these stops affect following vowels by lowering their F2 values in a manner consistent with a small degree of carryover labialization. With respect to the alveolar POA, such stops in K have been demonstrated to exhibit less consonantal coarticulation with the position of following vowels, especially when contrasted to the velar POA. Interestingly, though, the rate of coarticulation for alveolars in K is higher than the rate of coarticulation characterizing alveolars for several languages noted in the literature. The coarticulation patterns for alveolars discussed above are consistent with normalized vowel plots coded for preceding POA, as in figure 1. In this way, the data for alveolars demonstrate the manner in which two methods of acoustic-data analysis can be employed synergistically in the investigation of coarticulation patterns.

The data also suggest that the coarticulation patterns characterizing voiceless stops in the language appear to be the same as those characterizing voiced-stop allophones of nasal consonants, given the remarkable similarity in the locus equation data across the voicing-voiceless distinction. Such a "cross-voicing" similarity is not necessarily to be expected and has been shown not to exist in some languages (cf. Tabain 2002). In this case, the consistency between voiceless and voiced-stop locus equation data, apparent e.g. in figures 9 and 11, generally supports the claims on coarticulation based on the data for voiceless stops alone.

One final language-specific observation that may be gleaned from the above data is that, for the four speakers considered here, there is a remarkable consistency in overall locus equation patterns. This consistency demonstrates that the patterns uncovered are not due to speaker idiosyncrasies, and characterize the language more generally. Despite radically different absolute F2 values, the speakers sampled exhibited remarkably similar locus equation patterns for the three POA's in question.

With respect to non-language-specific findings, the above data are useful, as they pertain to fieldwork methodology. The study has shown that the quantification of coarticulation patterns through locus equations is a relatively straightforward technique. To arrive at the locus equations uncovered in this study, several hundreds (rather than thousands) of formant readings were taken. Once quality acoustic data are collected and a reliable method for formant measurement is selected, such readings are very easily ascertained. The readings can then be tabulated in spreadsheet format, and the locus equations can be

derived using statistical software. The entire process is straightforward and non-invasive, so that subject consent can be arrived at easily as well. In descriptions of under-documented sound systems, locus equation analysis could easily be used in concert with more traditional methodologies, as well as other acoustically-oriented methods, to provide a more complete description of stop consonants.

It is hoped that this study has demonstrated as well the usefulness of highlighting the entire locus equation perceptual space simultaneously, in order to reveal overall patterns of similarity across speakers. Such contrasts of overall patterns of locus equations for particular speakers, evident in figures 9 and 10, have not been employed in the literature. Such figures provide a pithy summary of CV coarticulation patterns in a language. If future field-based studies on locus equations were to include such figures, they could be contrasted with each other and with the figures presented here.

In conclusion, given the crucial role that CV coarticulation patterns play in the perception and production of stops by speakers of a particular language, it seems that the description of such coarticulation patterns merits inclusion (or at least the consideration of inclusion) in contemporary descriptions of undocumented or little-documented sound systems. Considering their demonstrated utility in helping to describe such coarticulation patterns, locus equations could serve as another important implement in the fieldworker's toolbox. With the effective statistical and speech analysis programs available to all with a notebook computer, this quantitative tool can be employed relatively easily, adding richness to phonetic descriptions of endangered languages such as K.

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