Dispersion in the vowel system of Pima

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Abstract

This is a report of a pilot study of the phonetic variation of vowels due to stress and syllable type in Pima, a dialect of O'odham. O'odham, along with several other Uto-Aztecan languages, has a five vowel system which appears unevenly distributed in two ways: its only front vowel is high, and it includes three high-back or high-mid vowels. This arrangement of canonical vowels appears not to reflect the influence of a drive for maximal dispersion of canonical vowels, something which has been argued to account for the frequency and type of vowel inventories cross-linguistically. Several properties of the allophonic variation observed in Pima, however, can be explained by appealing to just such a drive to maximize acoustic distinctness. Factors besides maximal distinctness must also be involved in controlling this distribution, however, as evidenced by the relative stability of this vowel system among Uto-Aztecan languages.*

1 Introduction

Cross-linguistic tendencies in segmental inventories invite explanation in terms of phonetic universals. Typological similarities between many languages which are historically unrelated and not in contact with each other are a strong indication that what is responsible for this similarity is some factor common to humans and human language, whether based on physiological, neurological, or some other factors. Typological tendencies that were observed in the composition and frequency of occurrence of vowel systems were seen relatively early in modern linguistics as reflecting some kind of universal tendency. It can certainly be no accident that a triangular five vowel system like /i, e, a, o, u/ or /i, ɛ, a, ɔ, u/, whose vowels are both relatively evenly dispersed throughout the available acoustic and perceptual vowel space and symmetrical with respect to the

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front/back distinction, is so common in languages of the world (Schwartz et al. 1997). In the face of broad generalizations like this concerning cross-linguistic tendencies, however, it is unclear what conclusions should be drawn from apparent counterexamples to the generalization. In the case of this study, the question which arises is, what should be concluded regarding universal tendencies from the existence of a language whose vowel system is significantly unlike the common five vowel system seen above?

In simple terms, the answer is that the situation must be more complicated than it seemed at first. A language which is typologically uncommon in some parameter certainly does not nullify the statistical tendency which can be observed for other languages with regard to that typological parameter. If something is stated as merely a tendency, even a strong one, some exceptions are to be expected. If an allegedly universal principle (or principles) is claimed to be responsible for the observed typological tendency, however, then some other principle (or principles), universal or not, must be at work in the exceptional cases in opposition to the principles responsible for the tendency. In the case of vowel inventories, typologically rare vowel systems show that the tendency toward a triangular five vowel system may be over-ridden for a particular language by, for instance, a drive for increased contrast, resulting in a larger vowel system introducing contrasts in rounding, tongue root position, or some other salient feature.

The alternative is to take exceptions to a typological tendency to show that the principles responsible for the tendency, though perhaps frequently occurring for some other reason, are not universal after all. Contrary to this, however, the universality of the principles responsible for the tendency may be supported if some other aspect of the typologically marked language shows the effects of the proposed universal principle, even if indirectly. This is analogous to the concept of emergence of the unmarked that is found with regard to phonological constraints in Optimality Theory: even in languages where the effect of a particular constraint is typically masked by the effects of other constraints, contexts may arise where the original constraint's effects are in fact seen. (McCarthy and Prince 1993)

This paper describes a pilot study of the vowel phonetics and vowel allophony of a language which has a typologically uncommon vowel inventory – Pima, a dialect of the O’odham language (ISO/DIS 639-3 code ood). The Pima vowel system includes five vowels, but rather than being arranged in a triangular system, they are arranged in what appears to be a very uneven way: /i ɯ u o a/, with only one front vowel and three vowels near the high-back corner of the vowel space. Even in a language like Pima, whose vowel inventory appears to show little influence of the principles which have been proposed to account for typological generalizations in vowel inventories cross-linguistically, there is evidence that these principles have consequences not directly related to the canonical vowel inventory. This paper also provides the first instrumental description of the Pima vowel system.

1.1 Theories of Vowel Dispersion

Simple theories of vowel dispersion, like the one proposed by Liljencrants and Lindblom (1972), model the cross-linguistic tendencies of vowel inventories by maximizing the Euclidean distance between each canonical vowel in a perceptual acoustic space consisting of the first, second and third formant frequencies in mel. The potential universal principle this is intended to model is the maximization of perceptual distinctness of the vowels in a vowel inventory: if the vowels are maximally distant from each other within the available vowel space, they are ostensibly easiest to distinguish from each other.

Although some predictions made by this model conform in general to the observed vowel inventories of natural languages, it has a number of insufficiencies. For example, it predicts only one set of vowels for a vowel inventory of a given size, and predicts that non-peripheral vowels (ie, vowels like /y/, /ɯ/, and /ə/ that do not occur on the edges of the acoustic vowel space) should occur with a much lower frequency than they are observed to have. With regard to the vowel system of Pima, this model by assumption does not predict languages with relatively uneven distributions of canonical vowels, especially vowel systems with unfilled sections of the perimeter of the vowel space. The fact that languages with these characteristics are not vanishingly rare shows that other principles besides maximal perceptual distinctness must be responsible for the distribution of vowels.

More complex theories of vowel dispersion, such as Lindblom and Maddieson (1988) and Schwartz et al. (1997b), improve on some of the weaknesses of the simpler theory. Lindblom and Maddieson (1988) propose that sufficient dispersion, rather than maximal dispersion, is what is required cross-linguistically. The Dispersion-Focalization model of Schwartz et al (1997b) includes forces which push vowels apart and distribute them evenly (such as maximal perceptual distinctness) as well as forces which sometimes cause vowels to prefer certain areas of the vowel space (such as articulatory simplicity, or auditory salience resulting from the convergence of multiple formants on or near the same frequency).

The theory of Schwartz et al. (1997b) is a measurable improvement on the simpler theory of Liljencrants and Lindblom (1972) in a number of ways. For instance, it allows for several different vowel systems with the same number of vowels. Also, relatively large unfilled areas of the vowel space are predicted to occur only in certain configurations. This is a desirable property, since languages whose vowel systems leave large unfilled areas of the perceptual space are in fact relatively rare. Although this model does fit well with many observed trends in vowel inventories noted by Schwartz et al. (1997a), the observed variety of vowel systems which have gaps or unfilled regions of perceptual space still does not perfectly match the predictions of this model.

From this mismatch of real-world typological observations and theoretical predictions, one could conclude that factors in addition to perceptual distinctness and auditory salience may also play a part in the distribution of vowels in the vowel systems of the world's languages,[1] or one

[1]A note on one possible additional factor is relevant here. In dealing with typological markedness and diachronic change, one might suggest that historical inertia is another force, along with maximizing perceptual distinctness and minimizing articulatory effort, in terms of determining the present range of variation in vowel inventories. Appeal to historical inertia does not add much to the model, however, unless it is assumed that historical inertia preserves a previous state of human language at which other factors, which are not currently active, shaped the vowel inventory. This is not an assumption that I believe can be made with confidence, but note that if this assumption is not made, then historical inertia can only preserve states of the language that were themselves a result of the same factors that

could conclude that the influence of perceptual distinctness and auditory salience is simply not present in some cases. If maximization of perceptual distinctness is a principle which is truly universal – that is, at work in every human by virtue of being a speaker of human language – but whose effect in terms of vowel inventories is masked in specific languages by other factors, then one other place where it might have an effect is in subphonemic variation of vowels: processes of allophonic variation might preferentially make use of the gaps in the vowel space, rather than cause phonetic overlap of neighboring phonemes. Effects of this nature are not normally listed for descriptions of vowel inventories, however, for example, in the UCLA Phonetic Segment Inventory Database (UPSID) (Maddieson 1984), which was the source of the database of vowel inventories used by Schwartz et al (1997b) to gauge the predictions of their Dispersion-Focalization model. To test whether perceptual distinctness shows an effect at the subphonemic level would require detailed phonetic information which might not already be published for a given language. This question of whether maximal perceptual distinctness affects allophonic vowel variation, though, could be posed in any language whose vowel inventory was not predicted by a theory of vowel dispersion, in order to determine if this principle has any influence in the grammar apart from controlling the vowel inventory (cf. Keating and Huffman 1984).

1.2 O'odham languages: Unpredicted by Dispersion Theories

One particular vowel system which is not predicted by the Dispersion-Focalization theory of vowel dispersion is that of the O'odham languages Akimel O'odham (also known as Pima) and Tohono O'odham (formerly known as Papago), Tepiman languages of Southern Uto-Aztecan. Pima is the dialect of O'odham spoken on several reservations near Phoenix, Arizona; Tohono O'odham is spoken farther to the south near Tucson, Arizona, and traditionally extending west into the southwestern portion of the state and south into Mexico.

The vowel system of these languages has been described qualitatively by many authors (Hale 1959, Saxton 1963, Hale 1965, Saxton and Saxton 1969, Hale and Alvarez 1970, Mathiot 1973, Saxton 1982, Saxton, Saxton, and Enos 1983, among others). These languages employ five modal vowels with two degrees of length.[2] The vowels include a high front unrounded /i/, a low central unrounded /a/, a mid back rounded /o/, a high back rounded /u/, and a high back unrounded vowel /ɯ/ (orthographically <e>).[3] The canonical phonetic realization of these vowels in Pima

would be at work in the language at the present time – and would this provide no additional explanatory power.

[2] Some authors, *e.g.* Zepeda (1983), refer to three degrees of length in Tohono O'odham: long, unmarked, and short. Tohono O'odham vowels with this third degree of length are argued by Hill and Zepeda (1992) to be unmarked vowels which have been demoraicized, and may correspond to devoiced off-glides observed in Pima on certain final consonants.

[3] The authors cited above vary in describing this fifth vowel as high back or high central unrounded. Most also follow the tradition among Uto-Aztecanists of using the symbol /ɨ/ to represent either a high back unrounded vowel or a high central unrounded vowel (see, for example, Langacker 1970), but not every description includes a statement as to the exact phonetic character the symbol /ɨ/ is intended to represent. Speakers of Pima have at least anecdotally described this vowel as identical to /u/ except in lip position, indicating that at least for some speakers of Pima it is likely to be phonetically high back.

(here taken to be in sentence-initial stressed syllables surrounded by glottal consonants, ie, either /h/ or /ʔ/) shows a large gap in the mid front region: there is no non-high front or central vowel, as can be seen from Figure 1. Here, the symbol <e> is used to represent /ɯ/, following the orthography. This and all subsequent plots have ellipses drawn at a diameter of two standard deviations along the principle axes of variation (to include 86% of the data).

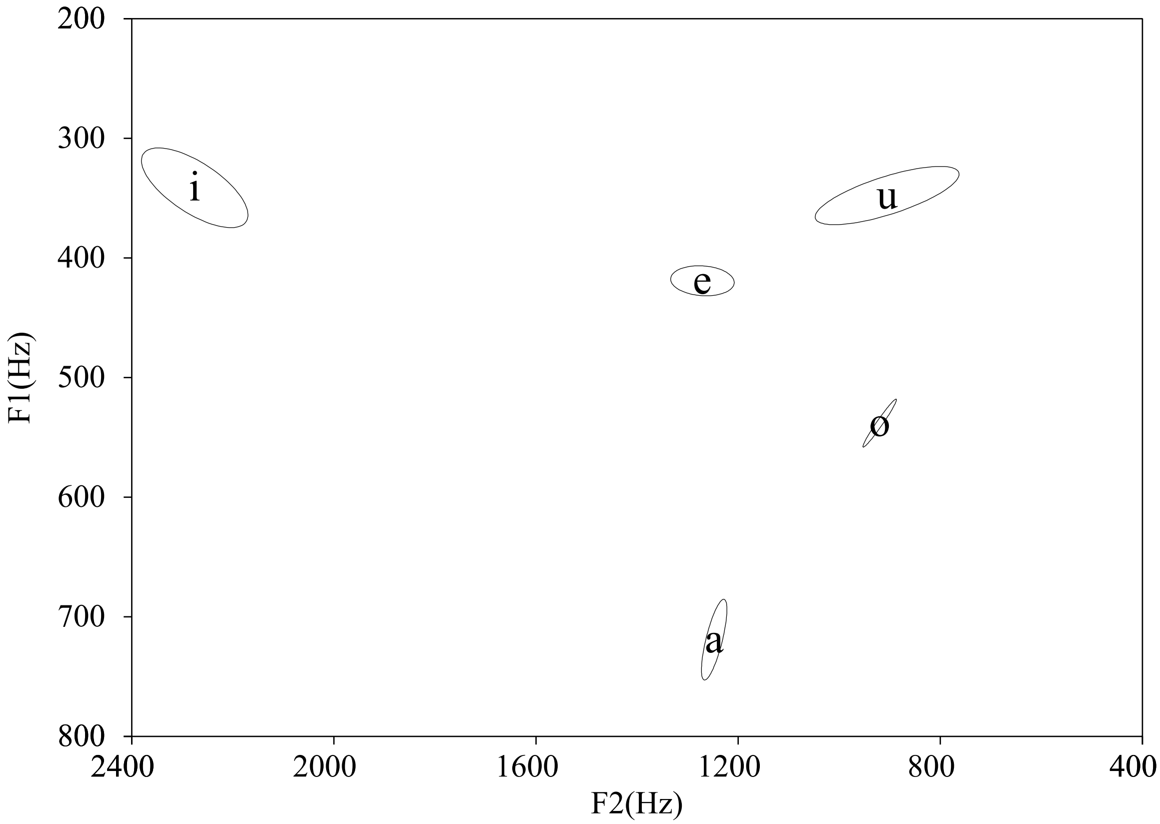

Figure 1. Measurements of the first and second formant frequencies of the canonical vowels of Pima.

This vowel system, or one which is quite similar, is also seen in at least five other Northern and Southern Uto-Aztecan languages: Chemehuevi (Southern Numic, described in Press 1975), Southern Paiute (Southern Numic, in Harms 1966), Northern Paiute (Western Numic, in Snapp, Anderson, and Anderson 1982), Northern Tepehuan (Tepiman, in Bascom 1982), and Nevome (Tepiman, in Shaul 1986). Langacker (1970) also reconstructs this system for Proto Uto-Aztecan.[4]

[4] The descriptions of these authors all include five vowels, though there is some uncertainty as to the identity of the vowel corresponding to the Pima /ɯ/. These authors almost uniformly use the symbol /ɨ/, following Uto-Aztecanist tradition (see footnote 4); not every description of the languages mentioned here, however, states whether this vowel in their language is back or central. Because of the close phonetic similarity of these two sounds, however, any vowel which is described as either high central unrounded or high back unrounded, or is represented by the /ɨ/

This vowel system is a departure in two ways from the two most common five vowel systems /i, e, a, o, u/ or /i, ɛ, a, ɔ, u/ seen in the world's languages (Maddieson 1984; Schwartz et al. 1997a). First, as noted above, O'odham has a gap in the mid front region of the vowel space; also, it has a concentration of vowels – /ɯ, u, o/ – in the mid to high back region of the vowel space. This concentration of vowel is odd because typically, if a language is missing a corner vowel (ie, /i/, /u/, or /a/), the high back corner of the vowel space is the location of the gap (Schwartz et al. 1997a).

Even the more refined theory of vowel dispersion presented in Schwartz et al. (1997b) does not predict a vowel system like this. Their model does predict a system very close to that of O'odham by predicting the systems /i, y, u, 'o', a/ and /i, ɯ, u, ɛ, a/, but these critically differ from the O'odham system in that the non-peripheral vowels in these systems share the backness feature of the missing mid vowel, in a sense compensating for its absence: in the system /i, y, u, 'o', a/, both the non-peripheral vowel /y/ and the "missing" /e/ are front, while in the system /i, ɯ, u, ɛ, a/, both the non-peripheral vowel /ɯ/ and the "missing" /o/ are back.[5] In O'odham, the non-peripheral high back /ɯ/ differs in backness from the missing mid front vowel. Although the typological frequency of this system might seem high because of the numerous Uto-Aztecan languages mentioned above that have it, these languages share a common ancestor which is reconstructed with this vowel system, making them biased as a cross-linguistic sample. Apart from these languages, this system is in fact cross-linguistically quite rare; the only language with this system in the 317 languages in UPSID, which is a more representative cross-linguistic sample, is Papago (ie, Tohono O'odham). That this system has persisted among Uto-Aztecan languages, despite its highly typologically marked status, is at the very least an indication that factors besides perceptual distinctness and focalization of formants can influence the distribution of vowels – in this case, diachronic inertia appears to have preserved the system in these languages, at least, against historical change, though it does not explain how it originally came to be. If distinctness and focalization are universal, they must be (or have been) superseded or overpowered by other factors at some point in the history of these languages.

If maximal distinctness truly is a universal principle and still has an influence in O'odham, however, processes of vowel allophony might plausibly take advantage of this unused vowel space, or act to more evenly fill the available vowel space: vowels near the gap (/i/, /a/, or possibly others) might vary more or might vary in a direction that fills the gap, and vowels near the crowded region (/u/, /o/, and /ɯ/) might vary less or might vary in a direction away from the crowded region. An instrumental answer to this question in one O'odham language, Pima, is the goal of this paper. The results show that although the process of vowel allophony in Pima does not exactly follow this simplistic hypothesis, maximal dispersion arguably still has an influence.

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symbol without a description, is considered to be "descriptively similar" to the Pima /ɯ/.

[5] Quotes surrounding mid vowels, such as 'o' here, are used in UPSID to indicate that the vowel was described by the source simply as "mid", rather than higher mid (represented as /e/) or lower mid (represented as /ɛ/).

2 Methods of the current study

This study represents the beginning stages of an attempt to phonetically characterize the process of vowel allophony in Pima. Data to date come from analog audio taped recordings of a single native speaker of Pima reading sentences at a self-determined pace in a sound booth. Data from additional speakers is obviously necessary to properly characterize the processes of vowel allophony in O'odham, and therefore research with other speakers is in progress. Measurements of the first four vowel formants were made of each vowel using the Praat software package after digitizing the analog recordings at 16-bit quality, 22,050 Hz, though data concerning only the first two formants will be discussed here. The statistical analysis was carried out using the StatView statistics package.

The frequency measurements were coded for vowel quality and length (i, a, o, u, ɯ; each long or short), occurrence in a syllable with primary stress or without primary stress,[6] occurrence in an open or a closed syllable, and the left and right segmental environment (up to and including the nearest vowel). For this study only short vowels were analyzed, both because long vowels are not found in all of these environments and because too few were recorded to examine length as a statistical factor. A two-way factorial Analysis of Variance (ANOVA) was performed for F1 and F2 for each vowel phoneme. Stress and syllable type were taken as independent categorical variables. Segmental context was not explicitly controlled, but was instead generalized over by measuring vowels in a variety of different contexts for each condition of stress and syllable type (similar to the procedure used in Keating and Huffman 1984). The number of distinct segmental environments and vowel tokens for each condition are shown in Table 1.

Phoneme	Open syllables		Closed syllables	
	Stressed	Unstressed	Stressed	Unstressed
/i/	9(23)	14(35)	13(38)	12(35)
/ɯ/	8(28)	10(24)	11(29)	8(104)
/a/	7(20)	12(36)	11(31)	10(150)
/o/	5(21)	25(72)	6(21)	7(21)
/u/	6(21)	8(28)	7(19)	7(24)

Table 1. The number of environments and vowel tokens for each statistical condition; format is # *environments(# tokens)*.

3 Vowel distribution

Compared to Figure 1, the vowel space becomes appreciably filled in when vowel tokens are included from a variety of prosodic and segmental environments, as can be seen in Figure 2.

[6] This study considers only two degrees of stress—primary stress *vs*. all other degrees of syllable prominence—though other authors (for example, Fitzgerald 1999 and Riggle and Munro 2004) have argued for an intermediate degree of stress in Tohono O'odham. In this study, the initial syllables of lexical (ie, content) words are taken to bear primary stress, as well as certain grammatical morphemes in a very small number of cases. The primary stress observed here refers to stress at the word level; the prominence of vowels within prosodic constituents higher than words was not controlled for in the current study.

Although the gap appears less dramatic in this view, the vowels still do not occupy all of the available vowel space. (Once again, the symbol <e> is used to represent /ɯ/, following the orthography.)

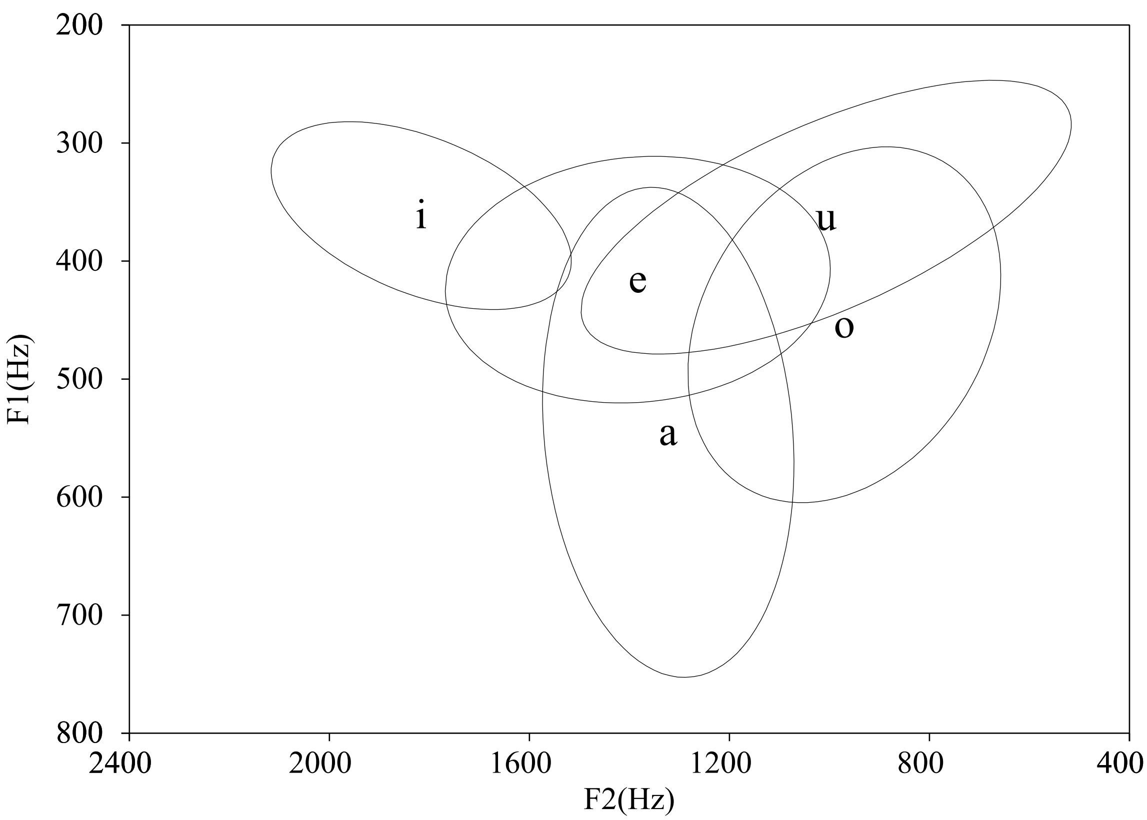

Figure 2. Frequencies of the first and second formants of the five vowels of Pima, taken from the recordings of vowels from a variety of segmental and prosodic contexts.

For comparison, the canonical English vowels (in this case, taken from the frame [h_d], pronounced in isolation rather than in sentences) for this fully bilingual speaker are shown in Figure 3, along with a scatter plot of the Pima vowel data.[7]

[7]This frame was used because of the ease of obtaining a range of vowel qualities using real-word prompts. Ideally, both the surrounding consonants would have been glottal or labial, rather than alveolar. These words were read rather slowly, however, and measurements of these vowels were able to be made at a point where the vowel formants were level and apparently unaffected by any transition to the following alveolar consonant.

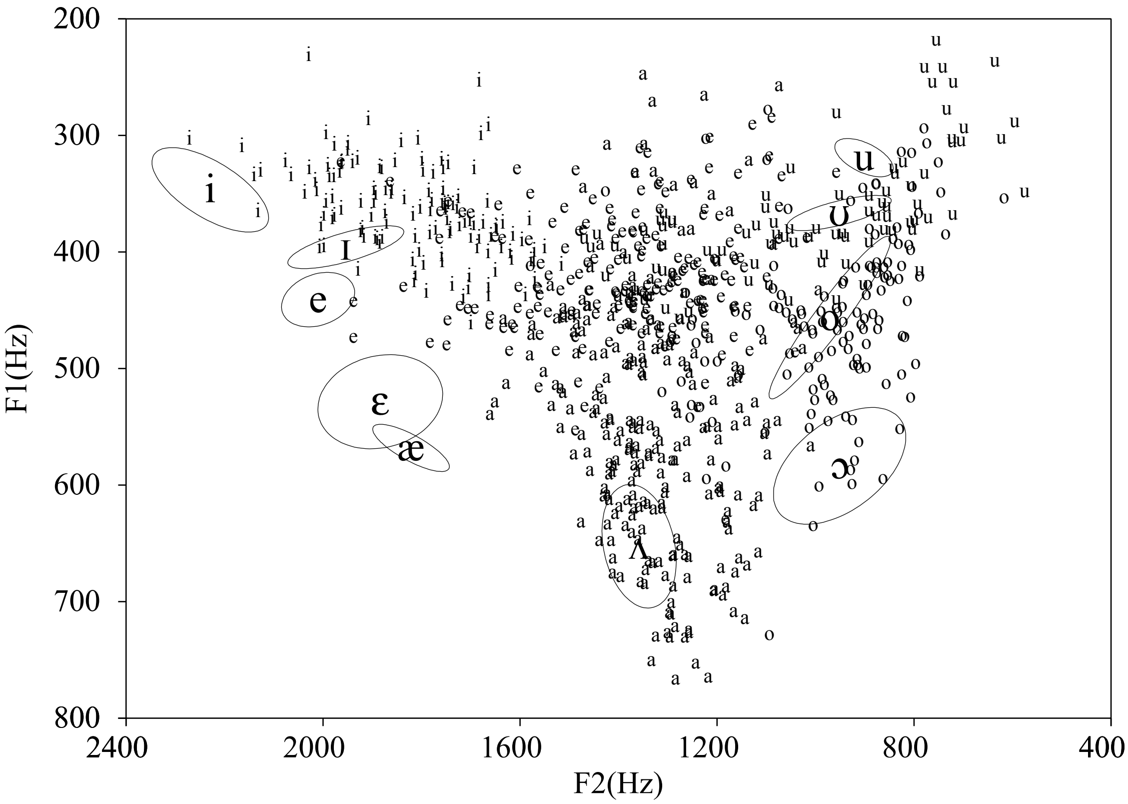

Figure 3. Scatter plot of the data used to generate Figure 2, overlaid with 2σ ellipses indicating the English vowels of the same speaker, taken from the frame [h_d] recorded in isolation.

None of the Pima vowel tokens is as front as the canonical English mid front vowels. In particular, though, it is clear from this comparison that even though the Pima /i/ and /a/ do vary appreciably, the Pima vowels do not fill the acoustic vowel space that is available to this speaker, as shown by the English mid front and low front vowels.

4 Vowel allophones: syllable type and stress.

The factors which were statistically examined for their effect on the first and second formant frequencies (F1 and F2) were syllable type (open or closed, ie, ending in a vowel or ending in a consonant) and word stress (primary or otherwise). Because ten ANOVAs were carried out – one per formant per vowel – a very conservative level of statistical certainty was used: $p < 0.005$ (which is .05/10; this is known as a Bonferroni correction). Significant effects of stress or syllable type were found only for the phonemes /a/, /u/, and /ɯ/.

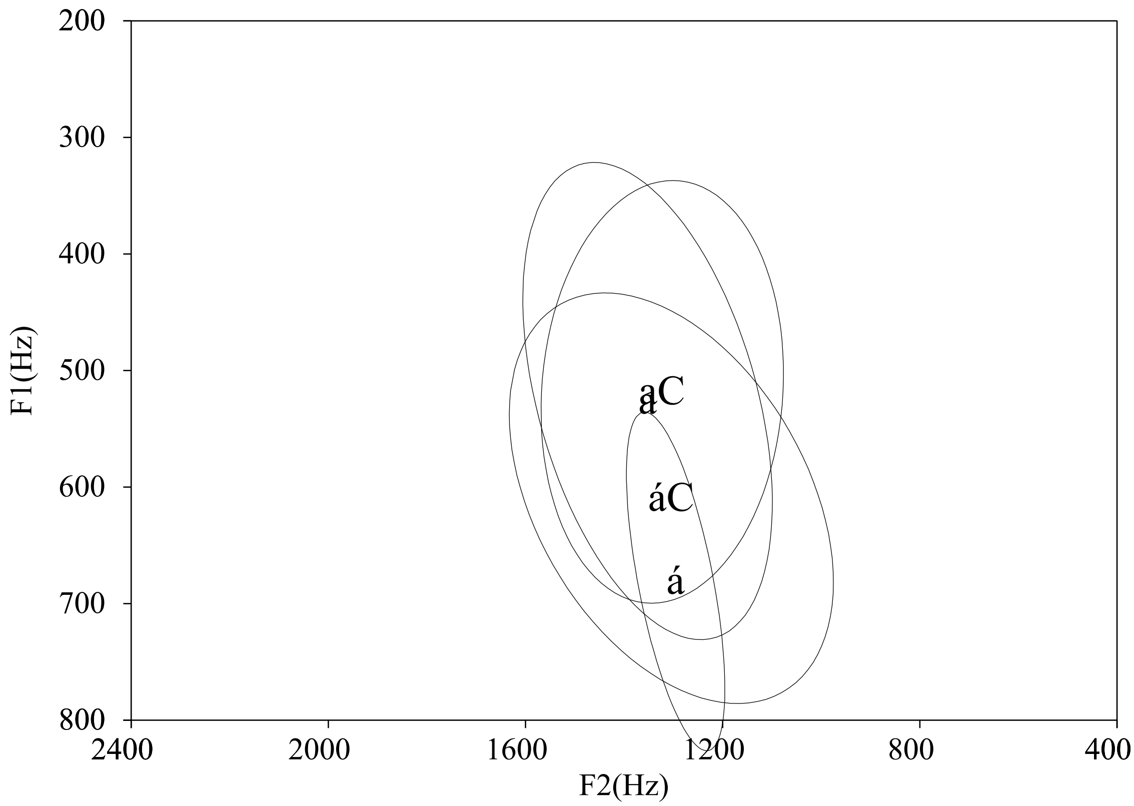

Figure 4. Ellipses indicating the variation of the first and second formants of the vowel /a/ in a variety of contexts. Symbology for this and the following figures, exemplified for the phoneme /a/: *á* open syllable, primary stress; *a* open syllable, non-primary stress; *áC* closed syllable, primary stress; *aC* closed syllable, non-primary stress.

For the phoneme /a/, an ANOVA indicated a significant effect of stress ($F(1,233) = 62.778$, $p < .0001$) on F1, though no significant effects on F2. This variation, taken to be a non-neutralizing reduction in unstressed syllables, fills in a portion – but only a portion – of the mid front space, and also results in partial overlap with the range of the /ɯ/ phoneme (cf. Figure 10 and Figure 12).

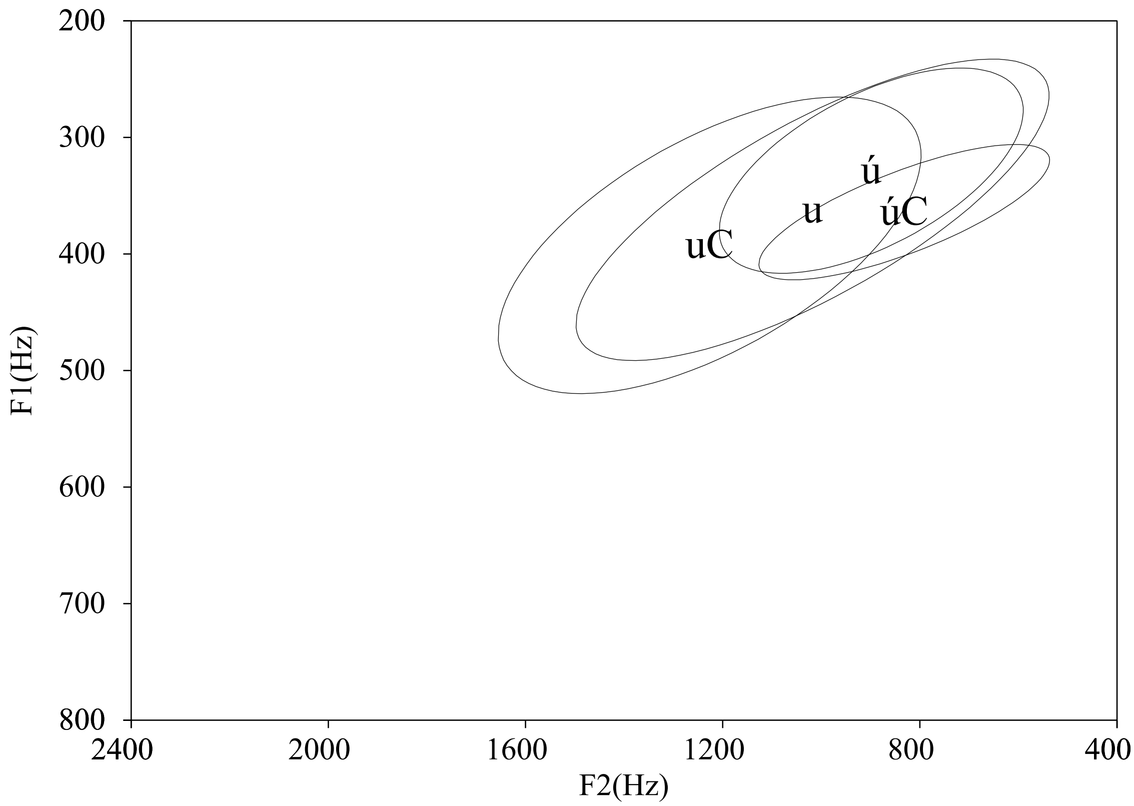

Figure 5. Ellipses indicating the variation of the first and second formants of the vowel /u/ in a variety of contexts.

For the phoneme /u/, an ANOVA indicated a barely significant effect of syllable type on F1 ($F(1,88) = 8.323$, $p = .0049$), a significant effect of stress on F2 ($F(1,88) = 37.604$, $p < .0001$), and a second order effect of stress and syllable type on F2 ($F(1,88)=10.845$, $p = .0014$). As with /a/, the reduction of /u/ in unstressed syllables results in partial overlap, though not neutralization, with /ɯ/.

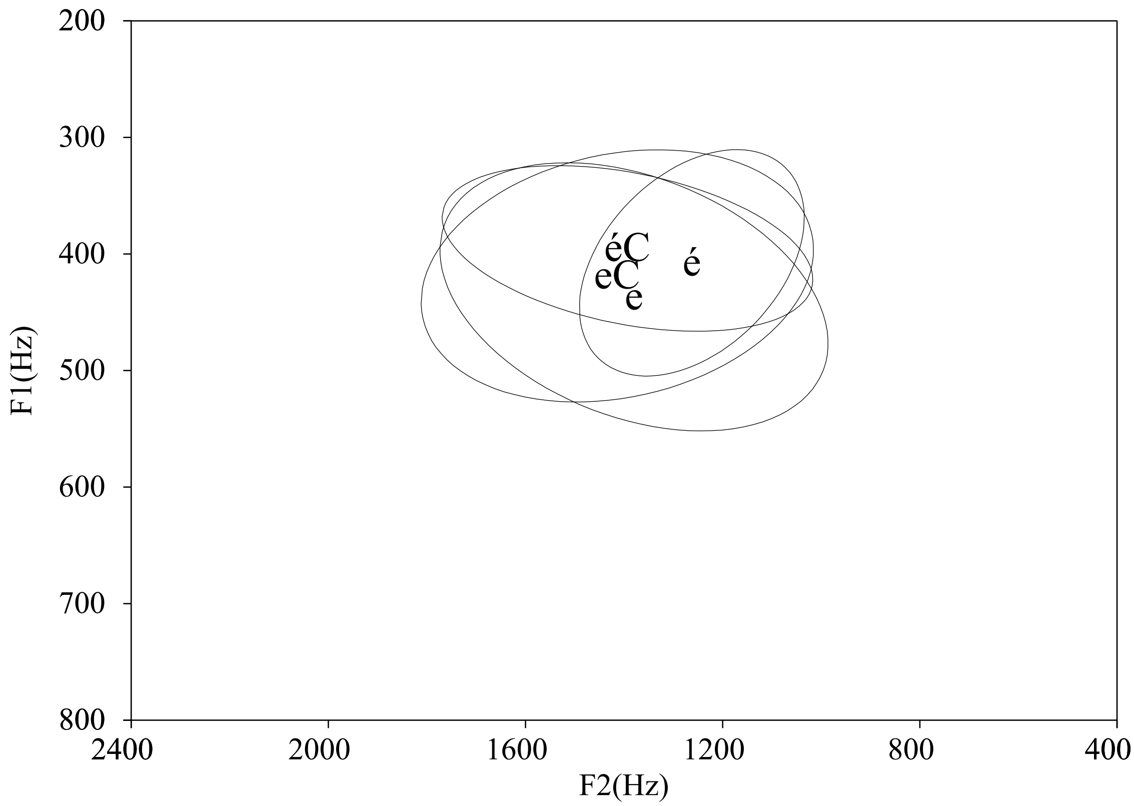

Figure 6. Ellipses indicating the variation of the first and second formants of the vowel /ɯ/ (written <e>, following the orthography) in a variety of contexts.

For the phoneme /ɯ/, an ANOVA indicated a significant effect of stress ($F(1,181) = 8.630$, $p = .0037$) on F1, though no significant effects on F2. This direction of variation is consistent with maintaining distinctness from /u/ – becoming lower or fronter, away from the high back /u/. It may be more likely, however, that this represents variation toward a mid or mid central target, since this generalization (ie, toward a mid central target, rather than away from /u/) would capture the observed alternations for /a/ and /u/, as well.

In general, then, most of the significant effects on these three vowels are due to stress. Each of these vowels becomes more mid or more central when it does not receive primary stress: /a/ tends to be higher and /ɯ/ tends to be lower in unstressed syllables, and /u/ tends to be more central in unstressed syllables. For /u/, there is also an interaction effect of both stress and syllable type: /u/ tends to be more central in unstressed closed syllables than in unstressed open syllables. The phoneme /u/ also showed the only effect due to syllable type alone: /u/ tends to be lower in closed syllables. Since the variances of the F1 values of /u/ in the four experimental conditions varied considerably (between 29.2 and 64.8), however, and since this result was just below the corrected probability value, re-evaluation of this result based on further data is necessary.

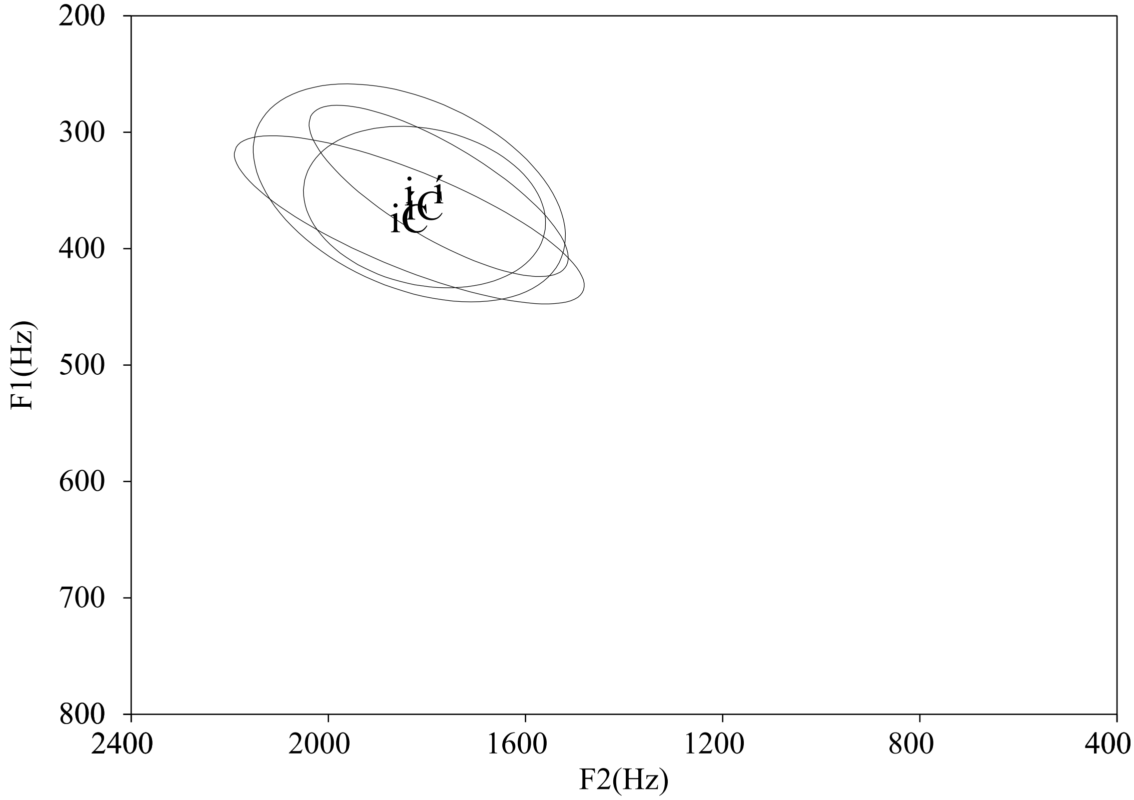

Figure 7. Ellipses indicating the variation of the first and second formants of the vowel /i/ in a variety of contexts.

The variation observed for the Pima /i/ vowel is shown in Figure 7. Although the F1 and F2 values for this vowel do vary over a relatively broad range, the centroids of the data in the different conditions do not vary considerably, and the ANOVA indicated that stress and syllable type have no significant effect. Segmental context may therefore be responsible for the observed variation in F1 and F2.[8]

[8] This is consistent with observations made concerning allophony between /i/ and /ɪ/ made by Suzanne Riggle (personal communication).

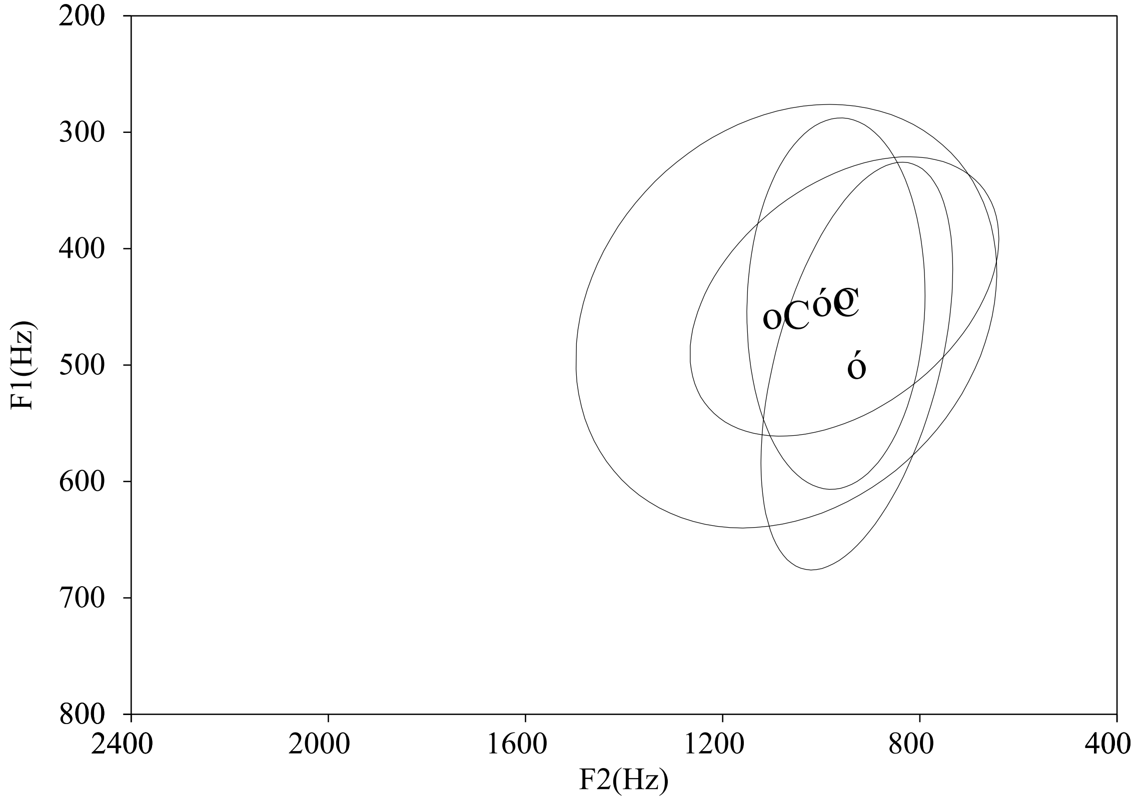

Figure 8. Ellipses indicating the variation of the first and second formants of the vowel /o/ in a variety of contexts.

The variation observed for the Pima /o/ vowel is shown in Figure 8. This vowel shows a great deal of variation in F1 and F2 within each of the test conditions. As with /i/, segmental factors rather than syllable structure and stress appear to condition most of the allophony seen here. Although the centroid values appear to vary more for /o/ than for /i/, the ANOVA again indicated that stress and syllable type had no significant effect. One striking feature of this data, however, is the wide variability of /o/ in unstressed closed syllables. In unstressed closed syllables, /o/ and /u/ appear to overlap considerably; /u/ in this context appears to be nearly a subset of /o/. This is easier to see by plotting all five vowels together by condition, as is done in Figures 9 through 12. Prima facie, such an overlap might appear to be an indication that the maximization of perceptual distinctness is actually not a driving factor here. This issue will be discussed further below.

Figures 9 through 12 show all five vowel phonemes together for each condition. Note that in each case, the gap in the mid-front region remains – that is, although the vowels do vary with stress and syllable type, and although some of this variation is statistically significant, this variation does not fill the space of the missing mid front vowel, nor does it more evenly distribute the vowels within any of these four conditions.

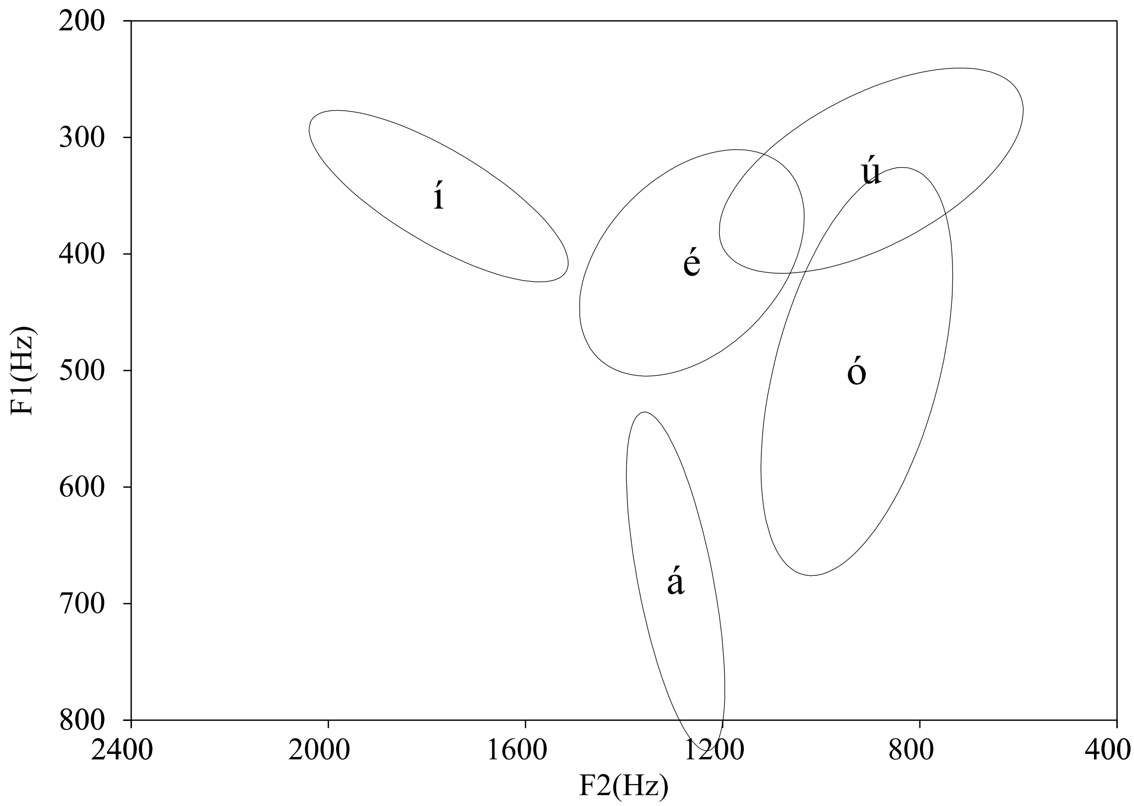

Figure 9. Ellipses indicating the variation of the first and second formants of the vowels of Pima in stressed open syllables representing a variety of segmental contexts.

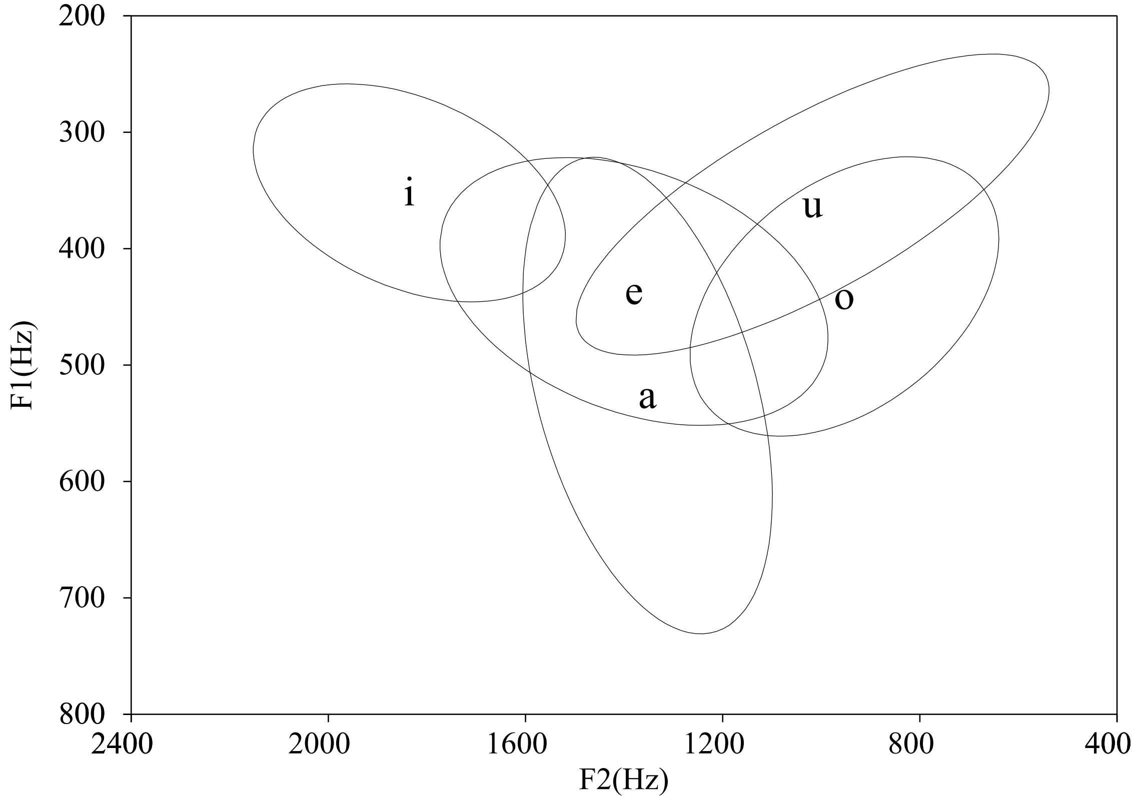

Figure 10. Ellipses indicating the variation of the first and second formants of the vowels of Pima in open syllables not receiving primary stress representing a variety of segmental contexts.

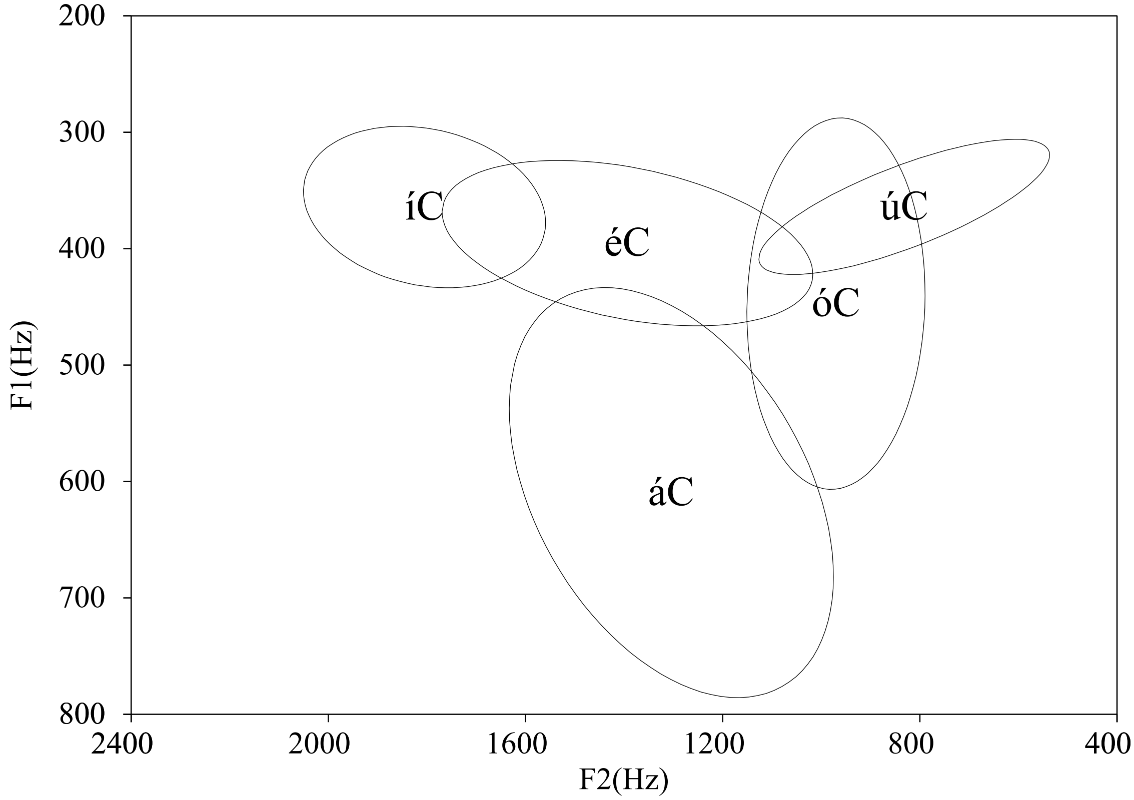

Figure 11. Ellipses indicating the variation of the first and second formants of the vowels of Pima in stressed closed syllables representing a variety of segmental contexts.

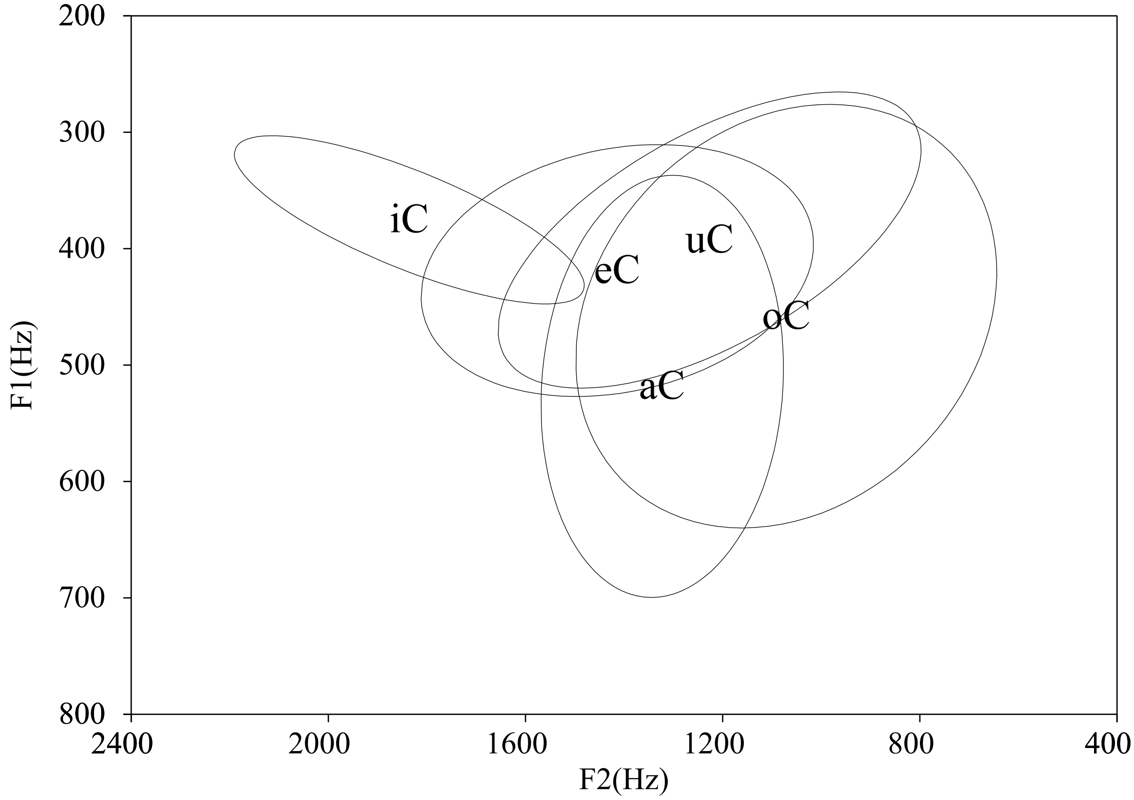

Figure 12. Ellipses indicating the variation of the first and second formants of the vowels of Pima in closed syllables not receiving primary stress representing a variety of segmental contexts.

Although several of the formant ranges of the vowels in these figures overlap appreciably, it should be pointed out that this variation is not completely neutralizing. Even non-native speakers of Pima are able to distinguish most of these vowels in most of these conditions. This brings out the nature of the current analysis in several ways. First, the ellipses in these figures indicate the range of F1 and F2 values for these phonemes for a range of segmental contexts. In a single segmental context, the formant values for any two vowel phonemes may not overlap. Also, it is possible that these vowels are distinguished by other factors not indicated here – by the higher formants or by duration, for example.

5 Discussion

As a pilot study, the results just presented should be taken as preliminary, and not necessarily identical to what would be obtained from a larger sample of speakers. Also, because of the nature of the data, it is not possible to conclude, for instance, that maximization of perceptual distance, for instance, is the primary motivating factor behind any of the differences in vowel quality that were observed. We can, however, see several points of variation which are at least consistent with maximization of perceptual distance being a driving factor. Further work is needed in order to show the results to be representative of the language as a whole (rather than just one speaker), and potentially complementary data could be sought to isolate maximization of perceptual distance as the driving factor. It is, however, possible to draw preliminary conclusions from what data there is.

5.1 Other descriptions of vowel reduction in O'odham

The results regarding the direction and type of vowel reduction presented here are slightly different from a previous description of vowel reduction for Tohono O’odham. This discrepancy arises because of the broad nature of the term ‘reduction’; the two descriptions are actually of different types of vowel alternations.

Crosswhite (2001), in a cross-linguistic study of reduction patterns, cites Hill and Zepeda (1992) as claiming that that /ɯ/, /o/, and /a/ reduce to [ə] in Tohono O’odham. The definition of vowel reduction used by Crosswhite restricts her to ‘cases where two or more underlying vowel qualities are neutralized in a stress-dependent fashion’ (2001:3). She felt that the alternation in Tohono O’odham met this requirement, but a closer examination of O'odham phonology and of the context of Hill and Zepeda's comment show that this in fact does not meet Crosswhite's criteria. Hill and Zepeda actually claim that /ɯ/, /o/, and /a/ are realized as a centralized release (written /^{h}/) when they are demoraicized (1992:367). This demoraicization appears to be associated more with a reduction in length rather than a reduction in stress, since Zepeda elsewhere argues that demoraicized vowels constitute a third degree of vowel length in Tohono O’odham (Zepeda 1983).[9]

The measurements reported here show that it is /ɯ/, /u/, and /a/ (rather than /ɯ/, /o/, and /a/) which reduce towards [ə] in unstressed syllables Pima, though these vowels are not completely neutralized, and /o/ partially overlaps with [u]. From Crosswhite’s perspective, this stress-dependent change would be considered ‘stress-dependent vowel undershoot’ (2001:3), not reduction, and so even this variation would have fallen outside the boundaries of her study.

5.2 Crowded vowels, unused vowel space, and maximal distinctness

As mentioned above, the fact that /o/ and /u/ appear to overlap in F1 and F2 in certain contexts at first might be taken as evidence that maximizing distinctness plays no role in vowel allophony in Pima – here are two vowels which undergo a change that apparently reduces their distinctness. A fact quite relevant to the interpretation of the phonological significance of this overlap, however, is that relatively few words in Pima appear to include /o/ or /u/ in an unstressed syllable. Smith (2002) reports that /o/ and /u/ are the two least frequent short vowels in a set of Pima texts, accounting for 3.6% and 2.7% of the phonemes, respectively. In contrast, /a/ was the most frequent phoneme overall (16.4%), with /i/ ranked third (8.1%) and /ɯ/ ranked fifth (6.5%).

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[9] These final demoraicized vowels in Tohono O’odham, apart from /i/, appear to be lost in final position Pima. Certain morphophonemic changes, however, such as the addition of certain suffixes, sometimes reveal their presence underlyingly.

The infrequency of /o/ and /u/ is even reflected in the data for this study. Although tokens of the phoneme /a/ were easily found in the four conditions examined here, a more thorough dictionary search was required to find words containing /o/ and /u/ in all four conditions, and these vowels remain the least frequent, as seen in Table 1.

The relative rarity of /o/ and /u/ changes the interpretation of their apparent overlap, and in fact this rarity could be a motivation for the overlap seen with these two vowels. Vowel reduction in this case can counter-intuitively act to maximize distinctness: by neutralizing or blurring some vowel distinctions, the remaining distinctions may be easier to perceive in certain contexts. The reduction of /o/ to [u], making /o/ and /u/ less distinct, would actually increase perceptual distinctness between these two vowels together, on the one hand, and the other three vowels in the Pima system, on the other. Since few words in Pima actually include unstressed /u/, this would introduce minimal lexical confusion while potentially increasing overall perceptual distinctness. This overlap, which may make the other vowels easier to distinguish from /u/ and /o/, is consistent with a drive to maximize distinctness, after all.

With /u/ being very infrequent and overlapping with /o/, some might propose that in this case these two vowels have undergone merger in the past – thus, the relative rarity of /u/ would be a result of their overlap, not a factor which permits overlap, as just discussed. This can be shown to be unlikely, however. Specifically, it might be proposed that a phonetic overlap between /o/ and /u/ at some point in the history of O’odham permitted /u/ to undergo partial merger with /o/, thus reducing the frequency of /u/ in the language. This explanation is unlikely, however, for several reasons. First, a partial merger of /u/ with /o/ would both reduce the frequency of /u/ and increase the frequency of /o/ in the language, yet Smith's (2002) data shows that /o/ is still only the fourth most frequent vowel. Second, there is no other evidence for such a merger within the history of Uto-Aztecan languages. To the contrary, the discussions of Proto Uto-Aztecan vowels in Langacker (1970), Miller (1967), and Voegelin, Voegelin, and Hale (1962) all have O’odham languages (exemplified by Papago) behaving conservatively, preserving the *o and *u phonemes of the proto language. Moreover, the frequency of phonemes in reconstructed lexical items does not appear significantly different from Smith's present observations. In Voegelin, Voegelin and Hale’s list of 171 cognates, *o and *u are still the least frequent short vowels, and although O’odham languages do delete some vowels from the historical forms, *o and *u are not lost more frequently than other vowels; the frequency of deletion of vowels roughly reflects the frequency of the reconstructed vowel phonemes.

The cluster of vowels in the high back corner is not limited to /o/ and /u/, however. If the O’odham fifth vowel /ɯ/ is accurately characterized as high back unrounded, then it, too, appears to be at least articulatorily crowded near these two other vowels, apparently unaffected by any drive for maximal dispersion. Indeed, Figure 1 gives the impression that /u/, /o/, and /ɯ/ are equally close to each other. There is some evidence, however, that /ɯ/, at least perceptually, may have a different status than the peripheral vowels /u/ and /o/. Disner (1984) notes that among complementary vowels – ‘vowel[s] of unexpected phonetic quality which [share] some of the features of [a] missing vowel’, (1984:144) – /ɯ/ is found much more frequently than other interior vowels, and in several perceptual studies is shown to be quite central and similar to /ɨ/. The phoneme /ɯ/ in Pima in Figure 2 appears to be quite central, and overlaps even with the high front /i/. Because of the frequent occurrence of /ɯ/ or /ɨ/ as a complementary vowel in systems which lack /u/, Disner conjectures that the high back region may be perceptually smaller than it appears acoustically (that is, that /ɯ/, /ɨ/, and /u/ are perceptually quite close). This would make the system of O'odham, with both /u/ and /ɯ/, especially marked from a perspective of maximal dispersion. If, however, the O'odham /ɯ/ patterns more like a central vowel perceptually, then it may not contribute as much to the crowding in the high back space seen with /o/ and /u/. Indeed, from the data in Schwartz et al (1997a), languages whose primary vowel system[10] includes the high vowels /i ɯ u/ or /i ɨ u/ account for 67% (48 out of 72) of the languages that have non-peripheral high vowels of any kind in their primary system.

Maximal distinctness therefore can be a reasonable motivation for the behavior of the vowels near the high back corner; the low lexical frequency of /o/ and /u/ results in minimal lexical confusion for the sake of maximizing distinctness between these and the other vowels, and the high back unrounded /ɯ/ may pattern more like a central vowel perceptually. The pattern of vowel reduction seen overall with the back vowels – /u/ and /ɯ/ reducing toward a mid central target, while /o/ reduces to overlap with [u] – is consistent with a drive to maximize distinctness, as discussed above. Maximal distinctness, however, is apparently not a sufficiently powerful motivation for vowels near the mid to low front gap to fill this gap completely. The vowel /a/ in reduced contexts, and to some extent the vowel /i/, partially occupy the empty region in the mid front area of the vowel space, but do not completely make up for the missing mid front vowel; this is particularly evident in the plot in Figure 3, as well as Figures 9 through 12. If maximizing perceptual distinctness is not sufficient to motivate /a/ or /i/ to vary allophonically with [ɛ] or [æ], then some other factor or factors may oppose a variation to this extreme. Crosswhite (2001) discusses several factors besides perceptual distinctness which influence vowel reduction which could be at work here. Quantal characteristics of vowels (as discussed by Stevens 1972) and focalization of formants (as discussed by Schwartz et al 1997b) also play a role, so dispersion does not need to, and probably cannot in any case, bear the entire explanatory burden for this distribution.

5.3 The Pima vowel system in the context of Uto-Aztecan languages

It is a challenge for theories of vowel dispersion, however, that a vowel system which is both typologically marked and predicted to be so rare has persisted in Uto-Aztecan languages to

[10] Schwartz et al (1997a) make a distinction between the primary vowel system and the secondary vowel system of a language. If two vowels exist in a system which have identical quality but different diacritics (such as for length or nasality), then one is considered part of the primary system and the other is considered part of a secondary system. If only one vowel of a given quality occurs in a system, regardless of diacritics (length, nasality, or any other secondary articulation), then that vowel will be considered part of the primary system. For example, Dagomba, which has the vowels /i a u i: 'e': a: 'o': u:/, would have the primary system /i 'e' a 'o' u/ and the secondary system /i a u/. Karok, which has the vowels /i ɛ a ʊ i: e: a: o: ʊ: ĩ ã/, has a primary system /i e ɛ a o ʊ/, a secondary system /i a ʊ/, and a tertiary system /i a/.

the extent that it has: at least six out of the 35 Uto-Aztecan languages listed by Grimes 2000, preserve this vowel system (taking Nahuatl as a single language), from different branches of both Northern Uto-Aztecan and Southern Uto-Aztecan.[11] Marked structures in language, whether typologically marked (ie, as seen from observation) or theoretically marked (ie, as predicted by theory), are most reasonably predicted to be unstable over time. Although something like diachronic inertia cannot be taken into account in typological models like the variants of Dispersion Theory presented above, it clearly has an effect on the overall number of languages observed with a given characteristic. It is for this reason that Maddieson, in selecting the languages to be included in UPSID, specifically chose at least one language from each language family, but imposed a minimum historical separation of 1500 years on related languages (Maddieson 1991).

Interestingly, however, the vowel systems of Uto-Aztecan languages which do differ from Proto Uto-Aztecan generally differ so as to more evenly fill the available vowel space. As mentioned in §1.2, the vowel system of Proto Uto-Aztecan is preserved in at least six Northern and Southern Uto-Aztecan languages: Chemehuevi, Southern Paiute, Northern Paiute, Northern Tepehuan, Nevome, and O'odham. At least seven other languages, however, differ from the proto system only by the addition of a mid front unrounded vowel: Comanche (Central Numic, described in Charney 1993), Panamint (Central Numic, in Dayley 1989), Shoshoni (Central Numic, in Miller 1972), Kawaiisu (Southern Numic, in Zigmond, Booth, and Munro 1991), Mono (Western Numic, in Lamb 1958), Huichol (Corachol, Sonoran, in McIntosh 1945), and Tübatulabal (Northern Uto-Aztecan, in Voegelin 1935). Southeastern Tepehuan (Tepiman, described in Willett 1991) has a system similar to these seven languages but with a mid back unrounded vowel rather than a mid front; Serrano (Takic, described in Hill 1967) differs only from these seven languages by the addition of three retroflexed vowels. As many as five others have developed an evenly-distributed five vowel system /i e a o u/ or /i ɛ a ɔ u/: Luiseño (Cupan, Takic, described in Hyde 1971), Mayo (Cahita, Sonoran, in Freeze 1990), Yaqui (Cahita, Sonoran, in Lindenfeld 1973), Eudeve (Cahita, Sonoran, in Lionnet 1986), and Tarahumara (Tarahumaran, Sonoran, in Thord-Gray 1955). To a large extent, therefore, as indicated by these languages, it seems that changes in the vowel systems of Uto-Aztecan languages have been in the direction of restoring maximal distinctness and an even distribution of vowels. This change may even be in its early stages in the O'odham languages, as well. Miyashita (2004) reports that the diphthong /ai/ in some dialects of Tohono O'odham is phonetically [e] in unstressed syllables, an alternation similar to one which occurs in Panamint (Dayley 1989) and Shoshoni (Miller 1972).

6 Conclusion

Although the results presented here show that O'odham languages, exemplified by Pima, do not utilize the entire available formant space under any conditions, vowel allophony in

[11]Perhaps others, on the other hand, would see this as a triumph of vowel dispersion theories, that 80% of the languages in this family have overcome whatever influence diachronic inertia may have in order to yield a more evenly-distributed vowel system. Different expectations would result from differing assumptions about the rate at which these languages should have moved toward a more even vowel system.

unstressed syllables does show effects which can be attributed to a drive to maximize perceptual distinctness. Vowels near the gap in the mid to low front region, particularly /a/, do vary, though not so as to make use of the entire gap. Vowels in the more crowded mid to high back region also appear to vary, and although this variation is not uniformly oriented away from the crowded region, the overlap of /o/ and /u/ in unstressed syllables can still be considered to maximize distinctness relative to the overall reduced system. The changes seen in the vowel systems of other Uto-Aztecan languages, and reportedly in some dialects of O'odham itself (Miyashita 2004), also show a tendency to more evenly fill the available vowel space. Data from additional speakers is awaited in order to make conclusions that are confidently representative of the speakers of the language as a whole, and possibly to isolate maximal dispersion as a significant, rather than merely plausible, factor in the phonetics of vowel reduction in Pima.

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