Vowel harmony domains and vowel undershoot

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Abstract

Much has been written on the reduction of vowels in unstressed syllables focusing mainly on Indo-European languages, but little has been said about the effects of vowel harmony on vowel reduction. Barnes (2006, 2007) and Crosswhite (2001) describe two types of reduction: prominence reducing reduction, which tends towards being categorical, and vowel undershoot, which generally produces a phonetic change in quality. In this paper, we are concerned with the second type. Gendrot and Adda-Decker (2005, 2006) claim that reduction is based on the phonetic duration of the vowel (rather than any phonological categorisation such as 'unstressed') and that in short syllables, the vowel converges towards a schwa-like quality. This paper gives more evidence to support this claim in languages that have no vowel harmony, but it goes further in claiming that reduction is blocked in vowel harmony domains. Within a harmony spreading domain, even in vowels of short duration, the quality of the vowel is not schwa-like. It retains the quality of the feature which is spreading. The result is that the reduction appears to be blocked. We will see several examples of this effect and discuss the possible causes. One important implication of this hypothesis is that it predicts the valency and privative vs. binary settings of features. It could therefore provide a useful input into discussions on the nature of phonological features.

1 Introduction

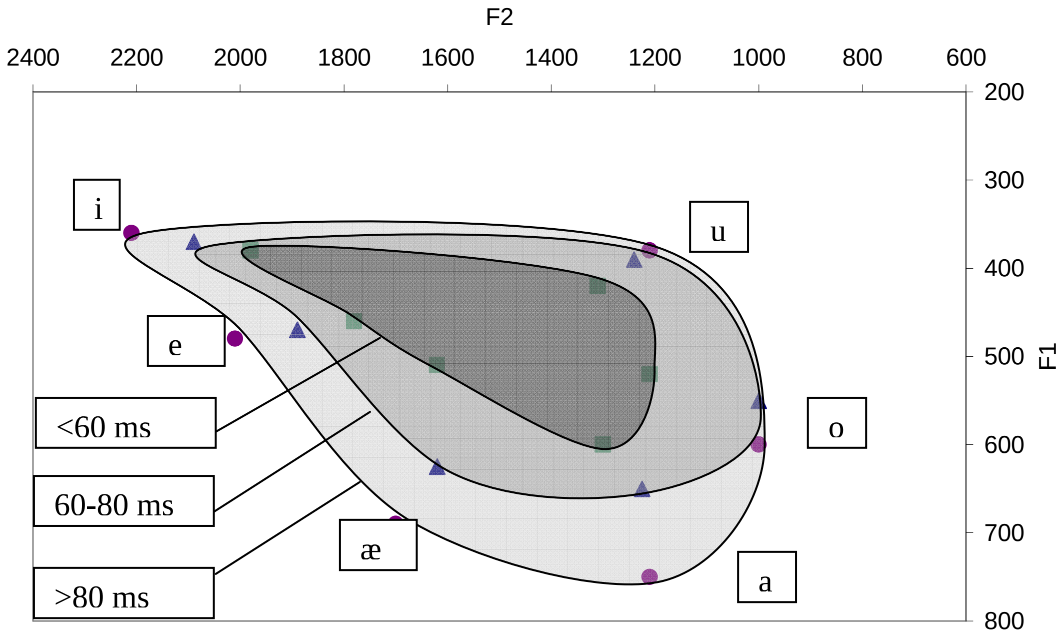
This paper examines the interaction between phonetics and phonology in languages where phonetic vowel reduction is affected by the presence of a phonological harmony domain. Crosswhite (2001) describes two types of reduction: prominence reducing reduction, which tends towards being categorical, and vowel undershoot, which generally produces a phonetic change in quality. In this paper, the word 'reduction' is used to denote the second type, i.e. a phonetic change in quality towards a centralised vowel, in short vowels only, caused by undershoot. We will not be considering any cases where the reduction involves a change in the phonological features associated with the vowel. In the examples in this paper, the underlying features form the target for the vowel, but the full quality of the vowel is not realised unless there is sufficient time for the articulators to arrive at the target, which takes approximately 80ms.

The main body of this paper is given over to the results from a number of languages of the acoustic measurements of F1, F2 and duration. We begin with the work of Gendrot and Adda-Decker on mostly Indo-European languages where reduction in both F1 and F2 is clear. Then we will consider a group of Chadic languages where the pattern appears to be different. We will begin with the Chadic language Kera (already cited in Pearce 2007b), and then examine the results from other Chadic languages. We will find that in this language family there is no reduction in F2. After some discussion on why this might be the case, we will move to examine other vowel harmony languages where the harmonic feature is different. In each language under investigation, the key questions will be: How much does the vowel quality vary? Which vowels vary and which do not? Does vowel harmony block the reduction? We will conclude that either the articulators reposition themselves for the duration of a harmonic domain, or it may be that the instructions for the domain are given before the instructions for individual segments, setting a starting point for each vowel in the domain. The paper will conclude with further discussion on the implications of these findings and areas for further research.

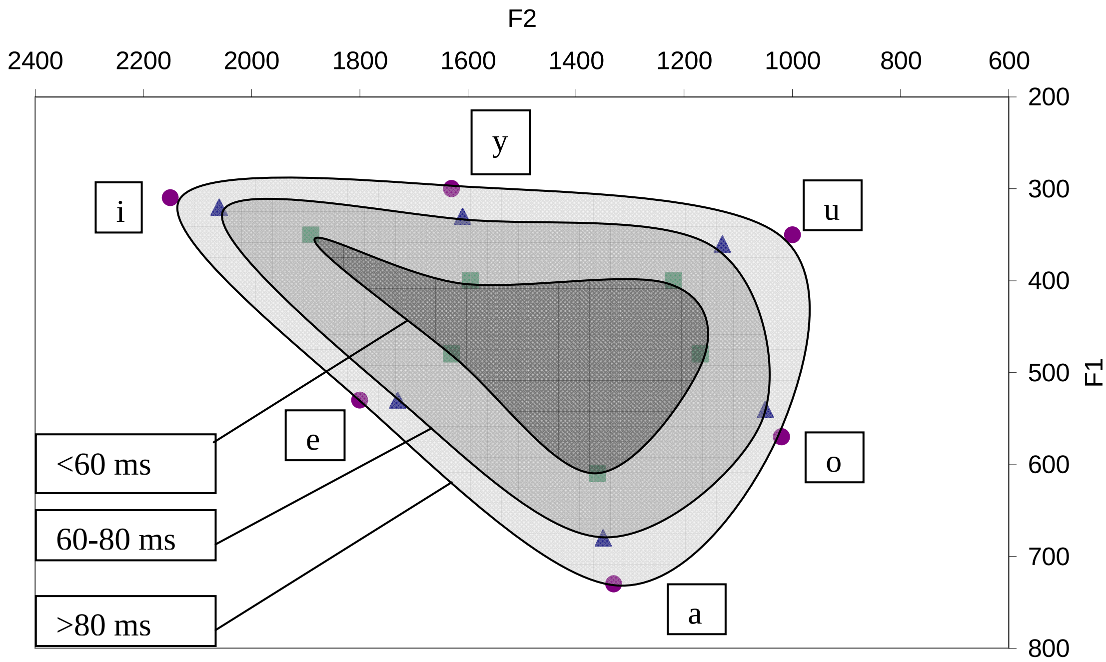
2 Vowel reduction polygons

Gendrot and Adda-Decker (2006) have studied vowel reduction in several languages, comparing the vowel duration with the first two formant values. They have come to the conclusion that in every language measured, and possibly in all languages, the F1 and F2 values will be nearer to the values for a schwa like vowel when the vowel is of shorter duration. Using a large corpus of data in each language, they have plotted these data for 8 languages including various European languages, Mandarin and Arabic. Some of these are redrawn below. Their research looked at all the vowels in each language, but in the diagrams below, only the vowels closest to Kera vowels are drawn so that a direct comparison is easier. (This makes no difference to the general pattern of concentric polygons). These diagrams are adapted from Gendrot and Adda-Decker (2006) and have also been reproduced in Pearce (2007b). The outside polygon with the lightest shading shows vowels which have a duration of longer than 80ms. The middle polygon represents vowels between 60 and 80ms, and the inside polygon which has the darkest shading represents vowels of less than 60ms duration.

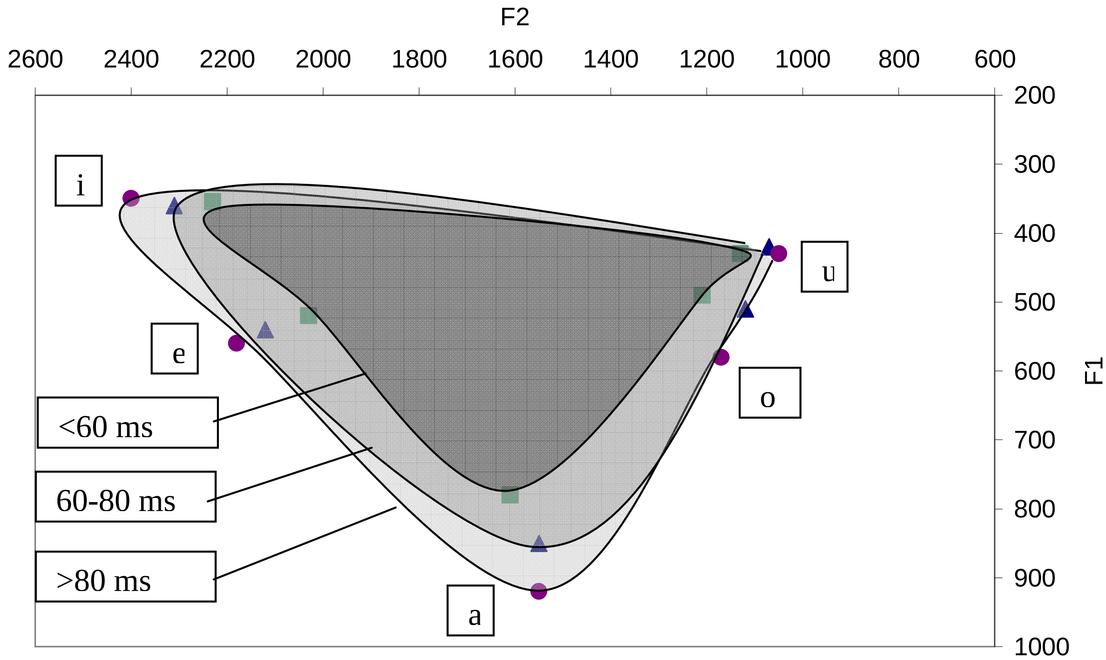
(1) *Measured mean average values of F1 and F2 for English vowels according to duration, data from Gendrot and Adda-Decker (2006), selected vowels only*



(2) *Measured mean average values of F1 and F2 for German vowels according to duration, data from Gendrot and Adda-Decker (2006), selected vowels only*



(3) *Measured mean average values of F1 and F2 for Mandarin vowels according to duration, data from Gendrot and Adda-Decker (2006)*



In each of the examples above, and in the others not shown here, there is a reduction towards a schwa-like vowel. Harris (1997, 2005) and Harris and Lindsey (1995) explain phonological reduction in terms of reduced vowels having a less complex representation which in centripetal reduction would mean a movement towards an unspecified, neutral 'vowel'. The quality of this sound would be equal to the carrier signal which Harris describes as 'a periodic waveform lacking spectral peaks, the acoustic effect produced by a neutrally open vocal tract'. Although we are not concerned here with categorical change, which would involve a compete reduction to schwa, the convergence described in this paper is towards the same neutral sound.

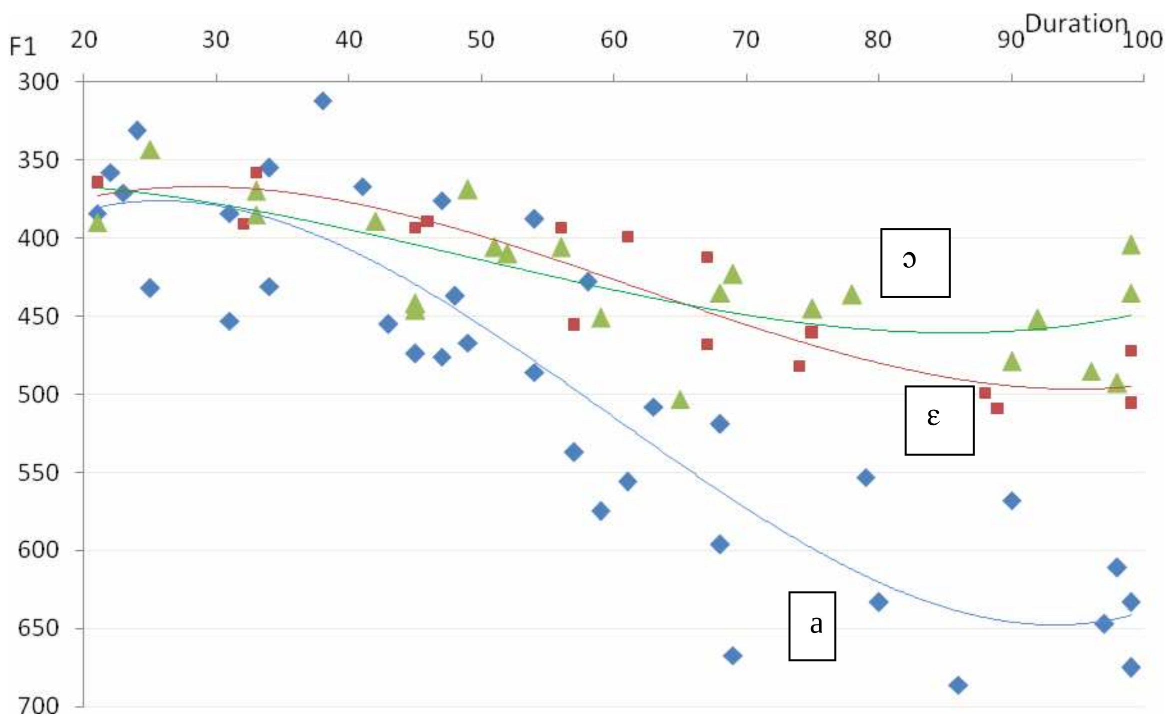
3 Vowel reduction in Kera and other Chadic languages

It is easy to assume on seeing the data from Gendrot and Adda-Decker that the same pattern of concentric polygons would apply in all languages, as they suggest. However, in Chadic languages, a different pattern emerges. Although there is F2 reduction, there is no F1 reduction in Chadic languages. We will begin with the Chadic language which I considered first, which is Kera. A short survey of other Chadic languages will follow, demonstrating that they all follow the same pattern.

Pearce (2003, 2007a) claims that Kera has six vowels: 3 high vowels /i, □, u/ and 3 non-high /e, a, o/. Each of the vowels has an F1 target, but this target is not reached unless there is sufficient duration for it to do so. The effect is minimal in high vowels, so we will concentrate on the non-high vowels. In shorter non-high vowels, the F1 value is small, resulting in a higher vowel, as the articulators have less time to reach their target. My claim is that this is due to vowel undershoot. The longer the duration, the closer the vowel is to the target. Once the F1 target value is reached, longer vowels will have the same quality. In all of this discussion on vowel duration, it is the phonetic duration which is in focus. The Kera phonology categorises vowels into long and short vowels, but this categorisation is not relevant here.

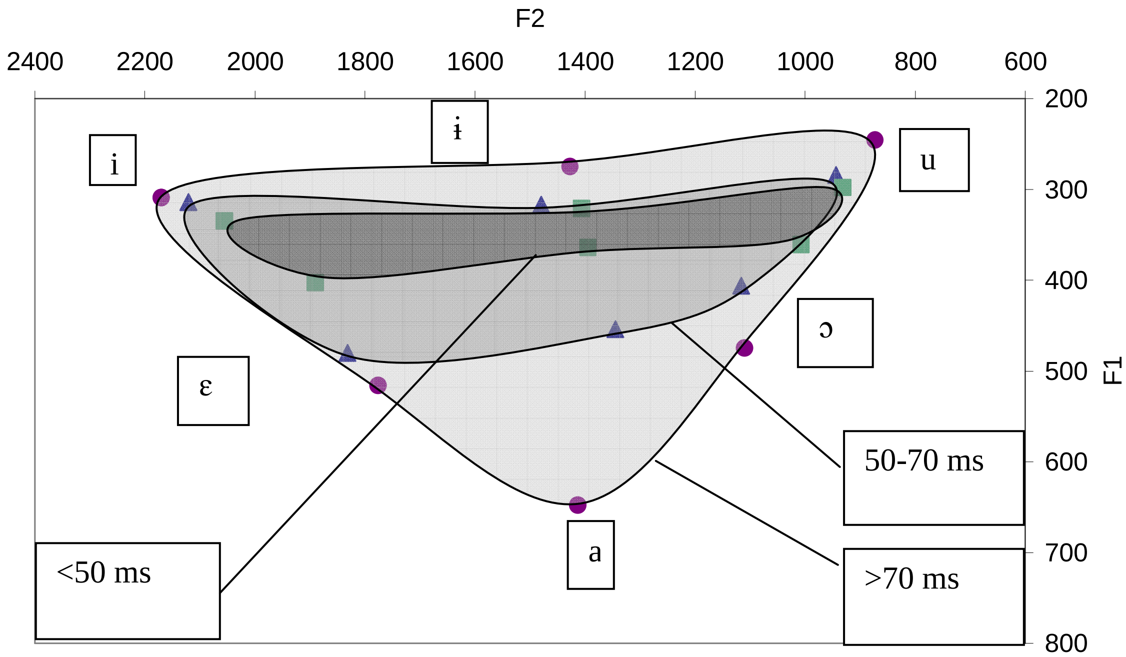
In the diagram below, which presents the vowels of one Kera speaker in a short discourse, the trend lines for each vowel suggests the speed of movement of the articulators. At a duration of 20-40 ms, very little movement is possible. At 40-80 ms, the slope of the trend line is greater. After 80 ms, the slope evens off as the target is reached. Clearly the /a/ target is lower, so the effect is seen best in this vowel.

(4) *Kera non-high vowels: Duration (ms) and First Formant (Hz)*



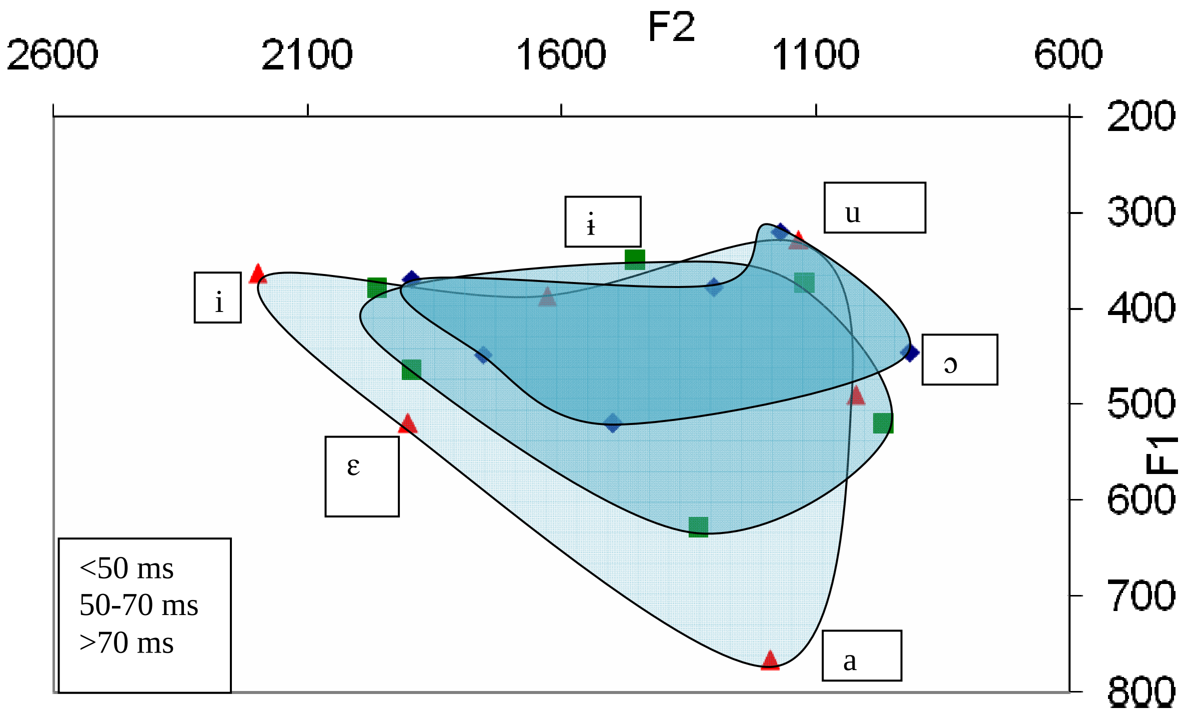
Given the apparent undershoot in Kera short vowels as seen in the diagram above, we might expect the same kind of reducing polygon pattern if we compare Kera with the languages which Gendrot and Adda-Decker considered, but the pattern is clearly and significantly different. The Kera polygon is shown below. For this diagram and all subsequent diagrams, the vowels are separated into three categories: > 70 ms, 50-70 ms, < 50 ms. The polygon for shorter vowels is still reduced, but the reduction does not occur in all directions. It appears to be exclusively reserved for variation in height (F1) and not in the front/round dimension (F2). The /a/ vowel has a major variation in F1. The high vowels do not significantly change either their F1 or F2 values.

(5) *Measured mean average values of F1 and F2 for Kera vowels according to duration*

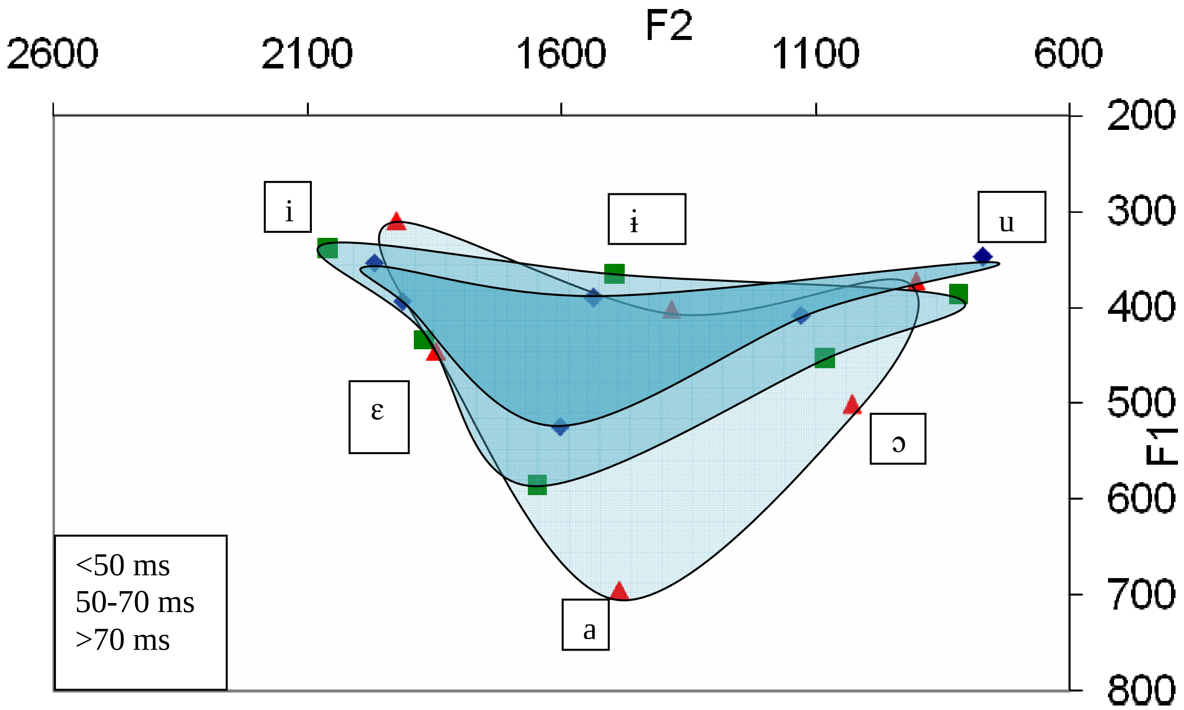


The question arises as to what is causing the difference in the reduction pattern in Kera. The reduction certainly seems to be varying with duration, but there appears to be a restriction on F2 reduction. One difference between Kera and the languages measured by Gendrot and Adda-Decker is that Kera has a rich vowel harmony system (Ebert 1974, 1979, Pearce 2003, 2007a). To test if this is likely to be the cause, we now turn to other Chadic languages. The following representative graphs show that all Chadic languages appear to have a similar pattern to Kera. In every case, the /a/ vowel allows considerable F1 variation and in no case is there a significant and consistent change in F2 values for any vowel. (In a few cases where data are lacking for a rare vowel, some variation occurs, but the difference is not statistically significant). The differences in shape between the polygons of each Chadic language are the result of differing target values for each vowel. This is language specific. Each graph is presented without further comment as they all demonstrate the same pattern. 17 Chadic languages were measured, but just a few representative languages are illustrated here.

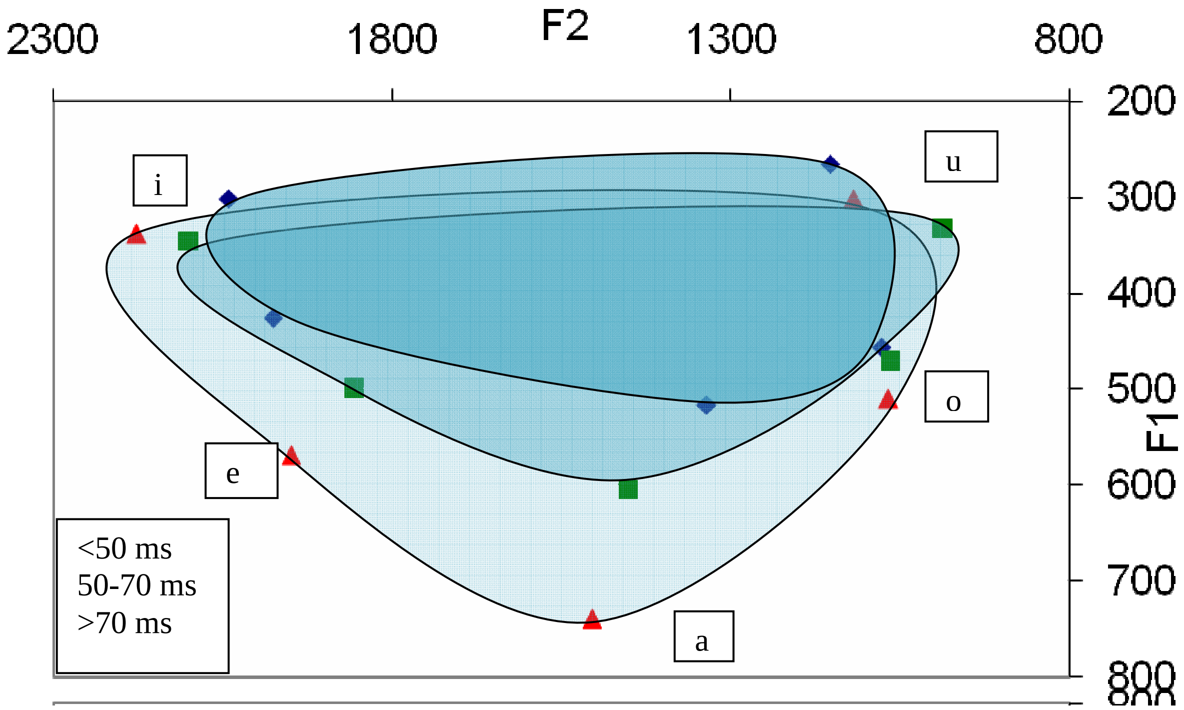
(6) *Measured mean values of F1 and F2 with duration for Mawa (Chadic) vowels*



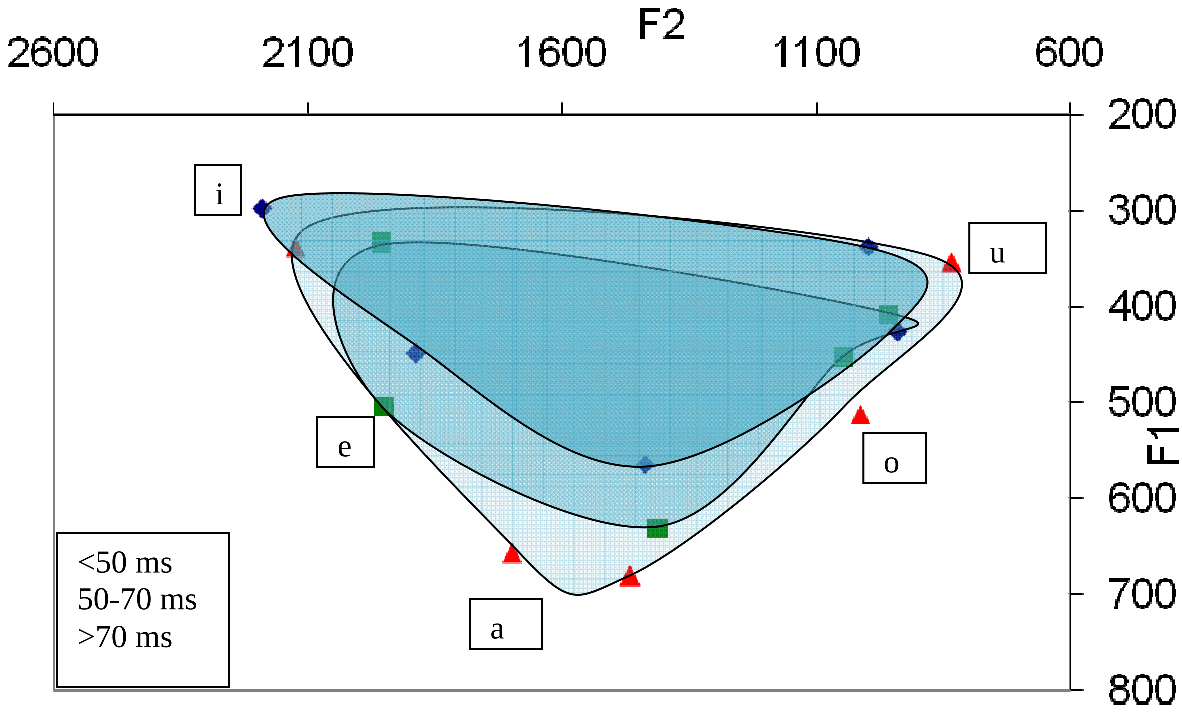
(7) *Measured mean values of F1 and F2 with duration for Moukoulu (Chadic) vowels*



(8) *Measured mean values of F1 and F2 with duration for Lele (Chadic) vowels*



(9) *Measured mean values of F1 and F2 with duration for Hausa (Chadic) vowels*



The 17 languages came from all branches of Chadic. There is a clear pattern in the reduction: The /a/ vowel reduces the most, high vowels do not move much and there is no significant reduction along the F2 axis. I claimed earlier that this effect in Kera is due to the complex vowel harmony system. But we now need to ask if all Chadic languages have the same sort of harmony. In fact, most have some sort of vowel harmony but the details appear to differ between languages according to descriptions. They do however share a common parent in Proto-Chadic. Some Chadicists have claimed that Proto-Chadic has only one vowel: the /a/ vowel. This contrasts with a schwa like 'non-vowel' (Wolff 2008). The claim has been made that other vowels were then developed through the processes of palatalisation and labialisation (These are known as 'prosodies' in Chadic circles). Whether we accept the 'one vowel' analysis or not, the processes of labialisation and palatalisation are still visible in many Chadic languages. In some, evidence for this is clear in the choice of consonants as well as the vowel harmony, such as in Lamang (Wolff 2008). In central-Chadic languages such as Mofu, linguists still suggest that there is only one vowel (Barreteau 1983). In Eastern Chadic languages, high vowels are rare, so claims have been made that these are really 'non-vowels' with palatalisation and labialisation processes causing the perceived vowel qualities (Roberts, p.c.). Some Chadic languages have also provided examples for a templatic approach to the analysis of CV patterns (Roberts 2002). This approach is only possible in languages where the vowel quality is largely predictable through harmony processes. All of these languages have some palatalisation and labialisation (which may be analysed as fronting and rounding harmony).

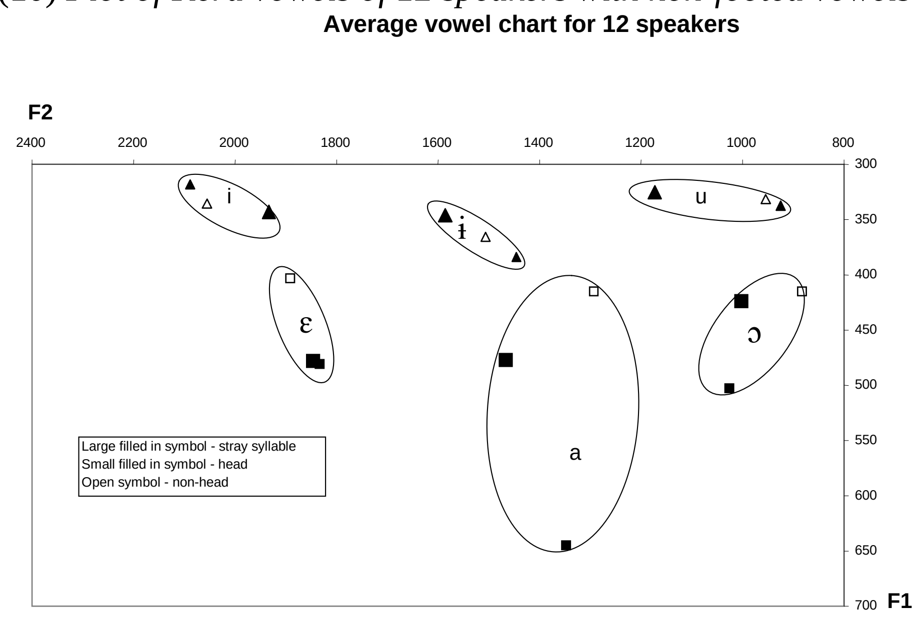
The Chadic polygons shown in this paper could lead us to suppose that the palatalisation and labialisation processes are still active in all Chadic languages even if the consonants no longer show any clear indication of these processes. If we suppose that the vowels are not underlyingly associated with features at the segmental level, (and that the surface vowel which is produced from no specification is /a/), then we can still generate the five or six vowel qualities that are found in each language from spreading processes acting at word level. This would include palatalisation, labialisation and in most languages height. The implication of these assumptions is that the spreading feature affects all segments, whether consonant or vowel, and that we are not dealing with two totally independent tiers.

Height harmony in Chadic is indeed the spreading of height rather than non-height. The Kera dominant height harmony Pearce (2007a) suggests this and the reduction facts in this paper confirm it. The only vowels that are left free to vary are the non-high vowels which are not specified for height. Although these vowels have a phonetic target which can produce a low vowel, this is only achieved if there is the time to reach the target. For these vowels, the articulators are only given the phonetic information at the beginning of the formation of the vowel. However, where the spreading process is working at stem or word level, the articulators are given instructions for the whole domain and this means that the articulators are either already placed in a forward or back position and remain there for the whole domain, or the non-neutral starting point is already defined for each vowel in the domain. Reduction does not take place because there is no movement back to a neutral position.

So the claim from these results is that in general, reduction will occur due to undershoot, but across harmony domains, the reduction is blocked. This is because within the domain of spreading, messages are sent to the articulators setting a starting position based on the feature that is spreading. This is not the normal neutral position. Only unspecified or non-harmonic vowels start from a neutral, relaxed, schwa-like position. From this new starting point, the articulators then move towards the target for each vowel as set by the features which are associated with each vowel. If the duration is long enough, the target will be reached. If the duration is short, the target may not be reached, but the vowel will still retain some of the quality of the spreading feature as the articulators were in position for the spreading feature at the start of the production of the vowel.

This analysis has certain consequences. Reduction should take place where a vowel is not in a spreading domain, but there should be no reduction where a feature is clearly spreading. One way to test this would be to try to look at reduction in single syllable words. However, single syllable lexical words in Kera (and probably other Chadic languages) have a minimum weight requirement so they must comprise of at least one heavy syllable. That means the vowel will have a duration of more than 50 ms and we will see little reduction as the vowel is of sufficient duration to reach the target. However, there are a few vowels in Kera which do not necessarily undergo spreading processes. These are the vowels in non-footed syllables which sometimes appear at the end of phrases.[1] Although height harmony usually does cover these vowels, they do not always agree in fronting or rounding with other vowels in the word. These vowels are not particularly short, typically they have a duration of about 50 ms, so we cannot expect a great deal of reduction, but if the claims in this paper are correct, we would predict that these vowels should show a little reduction in F2 values in contrast to other vowels of similar duration. This is hard to prove, but the following diagram of Kera vowels does suggest that these non-footed vowels may be reduced as we predict. When compared with the head and non-head vowels, the F2 values for the non-footed vowels appear to be more centralised. This is particularly noticeable in the /i/ and /u/ vowels. In this graph, the large filled in triangle or square denotes the non-footed vowels which we are focusing on here. The smaller symbols denote the footed vowels which do not reduce their F2 value.

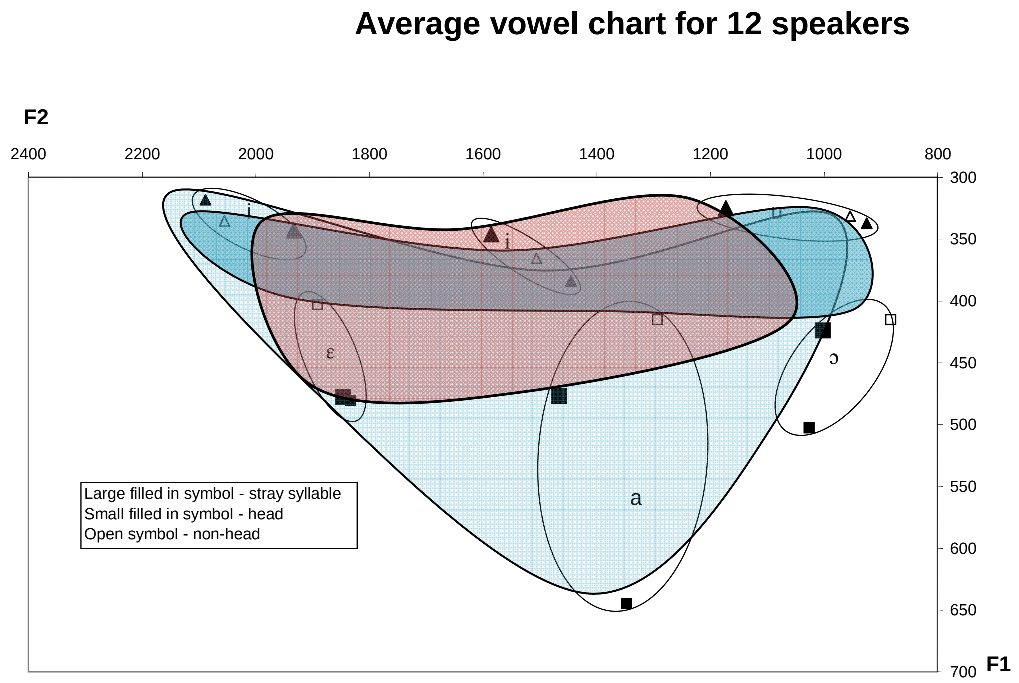
(10) *Plot of Kera vowels of 12 speakers with non-footed vowels*



The reduction is easier to see if we add a polygon linking the non-footed vowels. This can then be compared with the polygons shown before for standard Kera vowels.

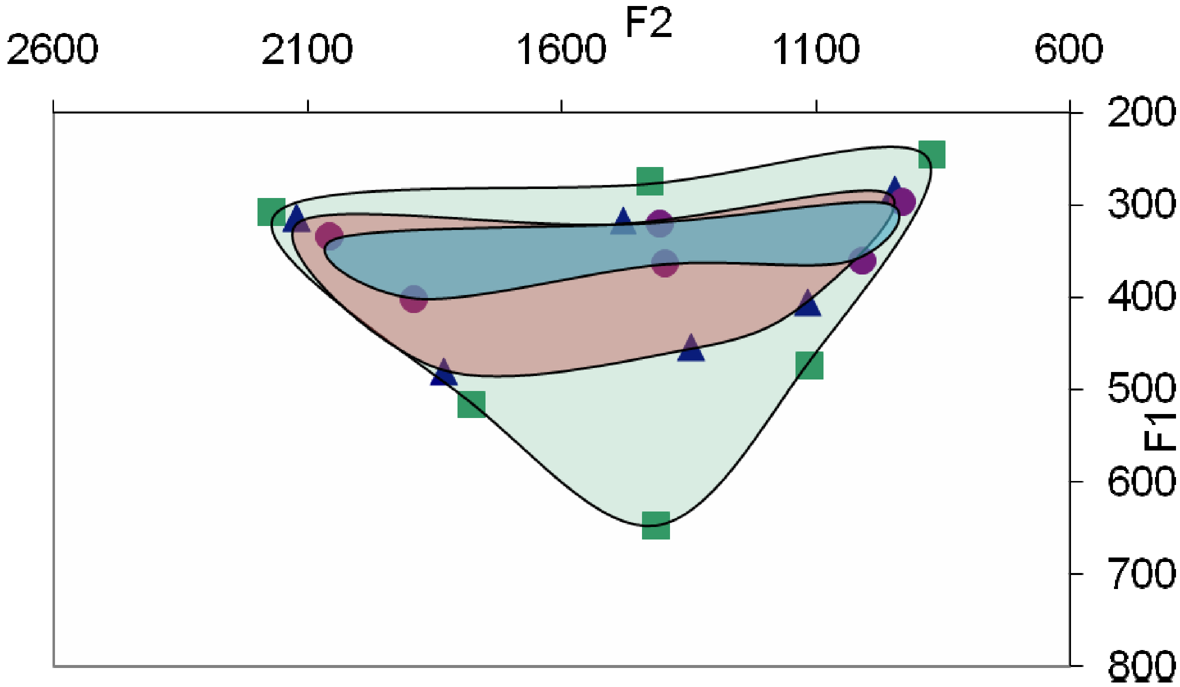
[1] For a detailed description of these syllables, see Pearce (2007b).

(11) *Plot of Kera vowels of 12 speakers with non-footed vowels showing reduction*



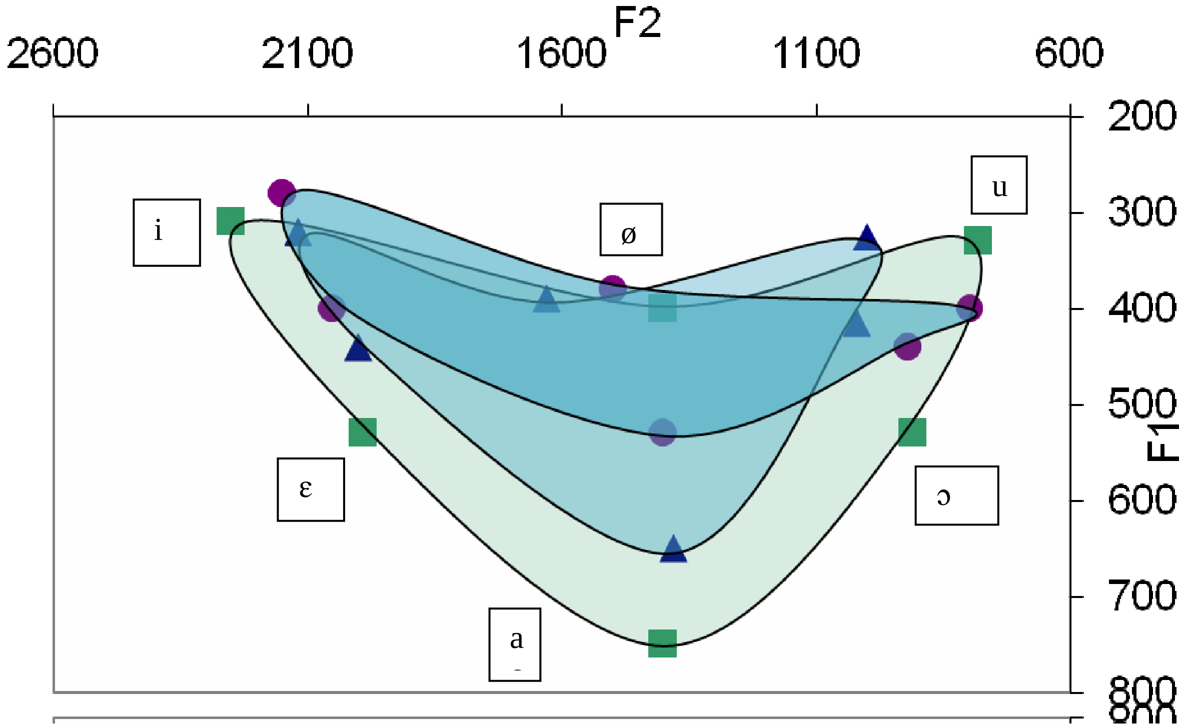
This contrasts with the graph for all vowels repeated below. Below, the /i/ and /u/ vowels show no significant changes, even for the duration of around 50 ms. Compare the polygons for non-footed vowels above and for vowels of duration 50-70 ms below.

(11) *Plot of Kera reduction polygon for all vowels*

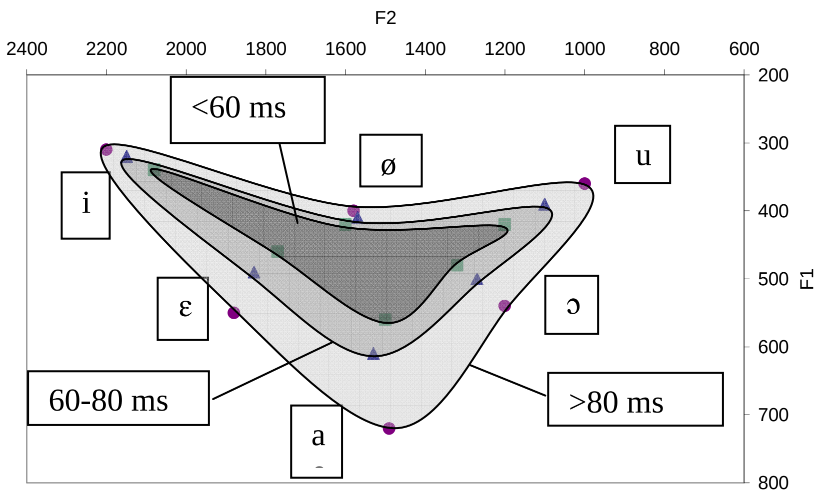


Although this is not proof that F2 reduction does take place in Kera where there is no spreading, it does provide supporting evidence for the claims being made here. There is one more piece of evidence from Kera speakers that also supports this analysis. A Kera speaker was recorded speaking French and the vowel polygons from this discourse are shown below. Note that for long vowels and for middle duration vowels, he appears to reduce the vowels as a French speaker would (see (13) below), but for very short vowels, he adopts the Kera system of not reducing F2.

(12) *Measured mean average values of F1 and F2 for French vowels according to duration, spoken by a Kera speaker, selected vowels only*



(13) *Measured mean average values of F1 and F2 for French vowels according to duration, data from Gendrot and Adda-Decker (2006), selected vowels only*



The Kera speaker when speaking French appears to be confusing two systems. However, if the analysis of this paper is correct, this is what we might predict. For long vowels, there is no reduction as the target is reached anyway. For medium duration vowels, unlike Kera, French has no vowel harmony. So the instructions for the articulators must be associated with each vowel rather than coming from a feature spreading domain. This leads to vowels that are more like Kera unfooted vowels which also receive individual instructions. The non-footed vowels have reduction in both F1 and F2. That means that in French as spoken by a Kera speaker, the medium duration vowels would also be expected to have some reduction. (12) shows that this is the case. For very short vowels, the Kera speaker cannot relate the vowels to anything in Kera. The French vowels are not in a harmony domain whereas Kera short vowels always are. The speaker does not have any precedent for F2 reduction, and if he hears the vowel with a large F2 reduction, he is likely to misinterpret the nature of the vowel. This sometimes happens in the French of Kera speakers (so the /i/ vowel in 'president' is perceived as a schwa and one version of the loan into Kera is *persədaŋ*), but if they are aware of the French orthography and know which vowel the target should be, they are then liable to produce the vowel in the same manner as they would in Kera with no F2 reduction.[2] When the speaker produces the vowel with no F2 reduction, this produces the third polygon for short vowels which looks like the Kera system rather than the French system.

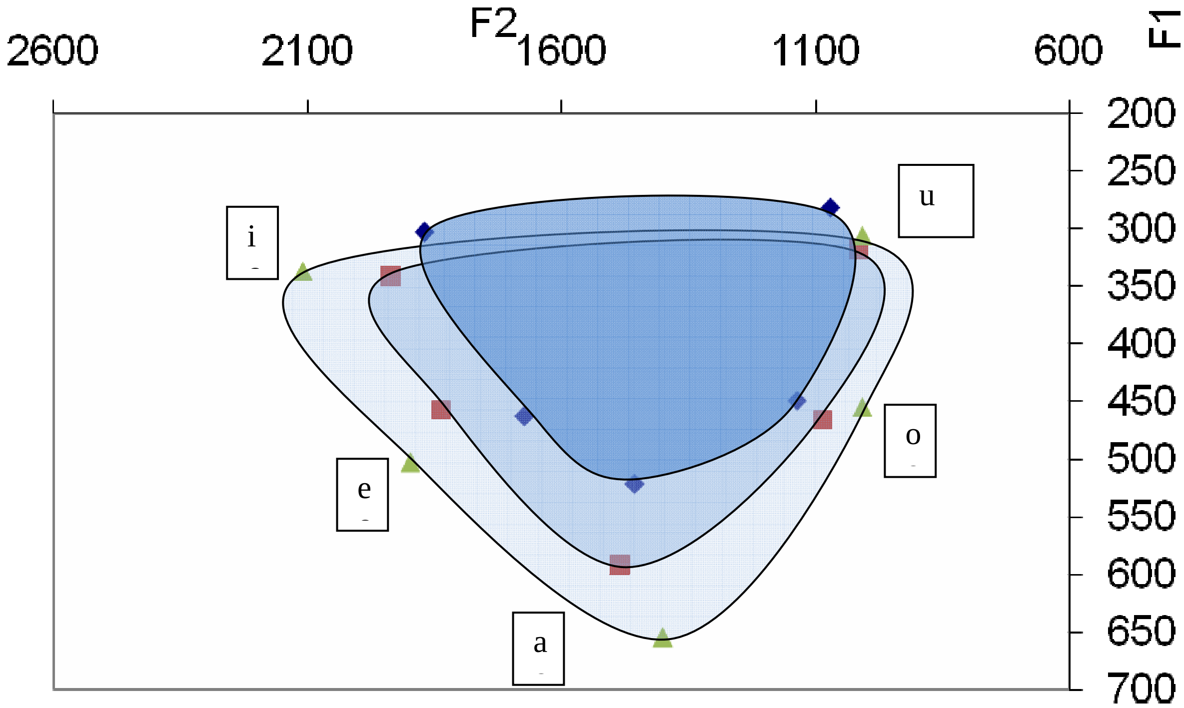
4 Other types of vowel harmony

If the claims presented here are correct, then we should see the same effects in other types of vowel harmony languages. This research is work in progress, but the results so far suggest that the same principles apply to other types of vowel harmony.

Mao is an Omotic language spoken in Ethiopia. It has a limited amount of fronting harmony within the root. We look first at the reduction of vowels which are not in a vowel harmony domain. As expected, there is a reduction of F1 and F2. The point of convergence appears higher than in the languages we have looked at so far, but with further observation we note that the high vowels are not particularly high on the F1 scale, so this point of convergence might still be roughly the same as for other languages.

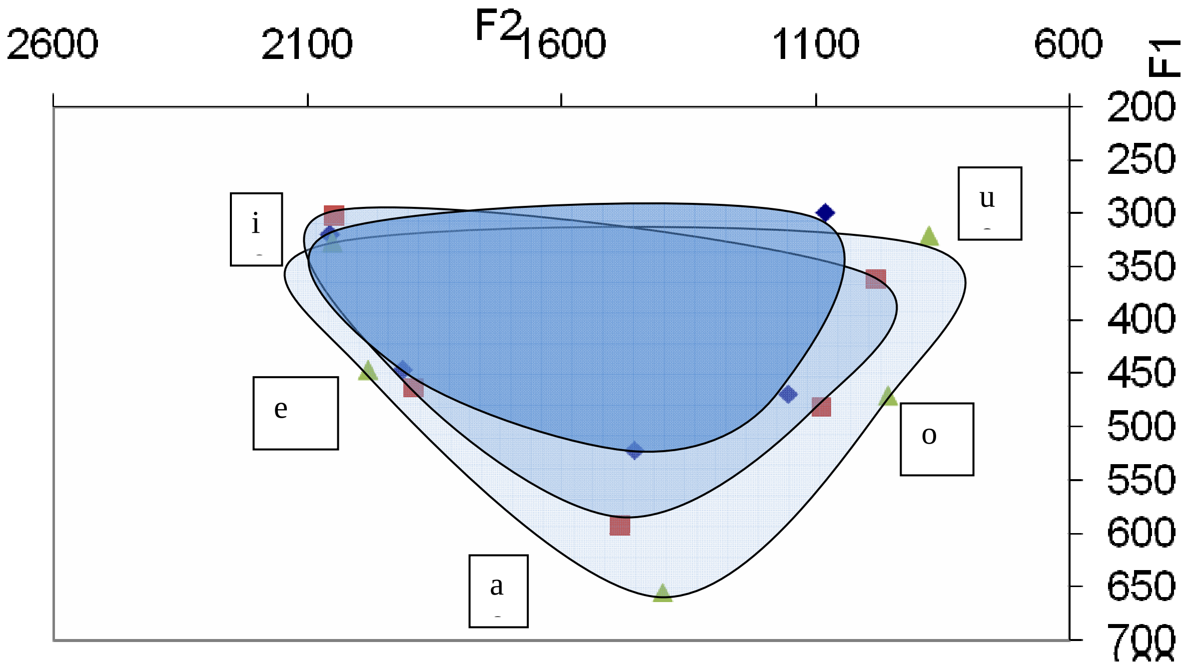
[2] They may also try to impose a certain amount of vowel harmony on the other vowels in the word, so 'president' could also become *president.*

(14) *F1 and F2 for Mao vowels according to duration, (recordings: Michael Ahland)*



We now consider the vowels which are in a fronting harmony domain. These are just the two front vowels, but in order to complete the polygon, the other three vowels are included even though they are not in a harmony domain. For the two rounded vowels, the data included here are taken from words where there could be rounding harmony as the vowels happen to agree. However, the researcher who gave me the recordings has informed me that the harmony does appear to be fronting harmony rather than rounding harmony. Note that the front two vowels do not have the same kind of reduction as before, so the polygon appears to converge towards the left. This is exactly what we would predict if fronting harmony is affecting the reduction.

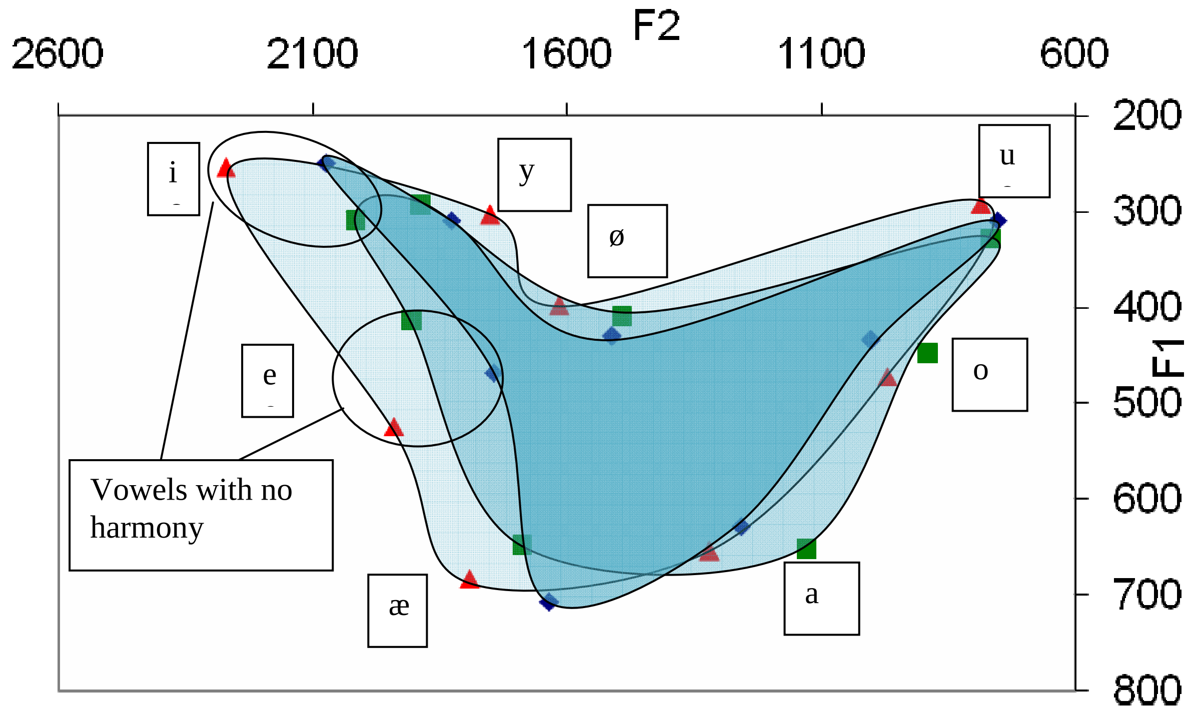
(15) *F1 and F2 for Mao vowels according to duration showing fronting effects*



So Mao confirms the claims made in this paper.

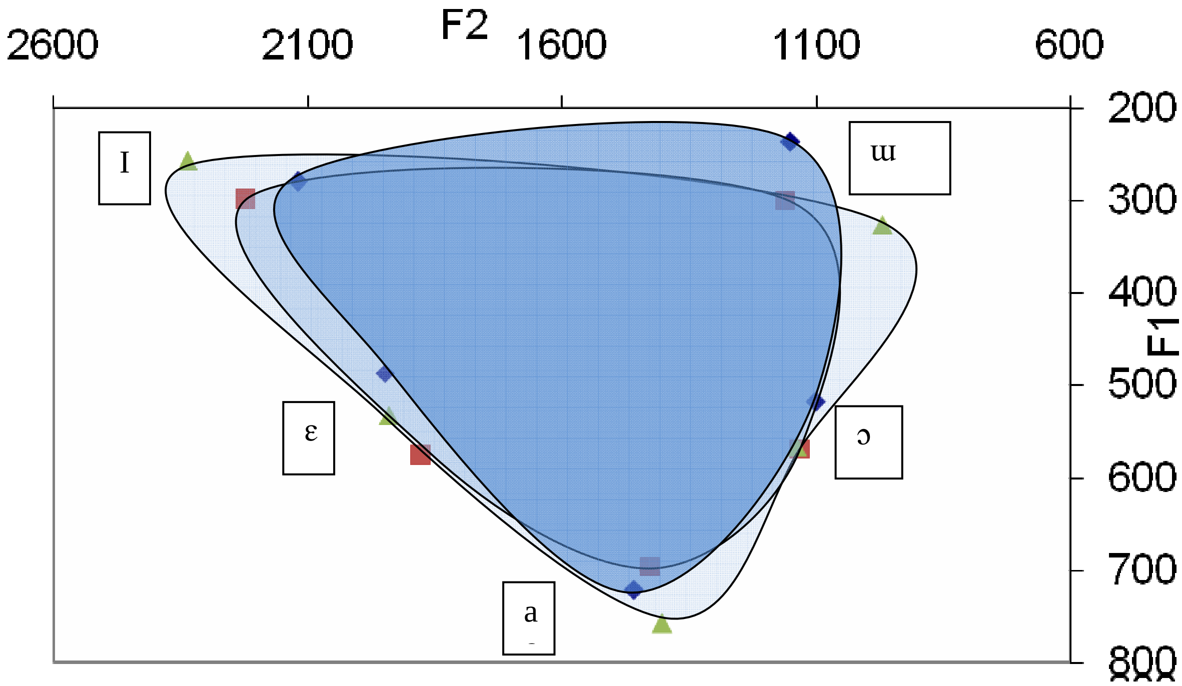
Finnish is also known to have an interesting vowel harmony system. There is a front/back harmony system with the addition of two neutral vowels /e, i/. So we would predict that these two vowels would allow more reduction than the other vowels. In the diagram below, these two vowels are circled. It is clear that they do allow much more reduction than the other vowels.

(16) *F1 and F2 for Finnish vowels according to duration showing neutral vowels*

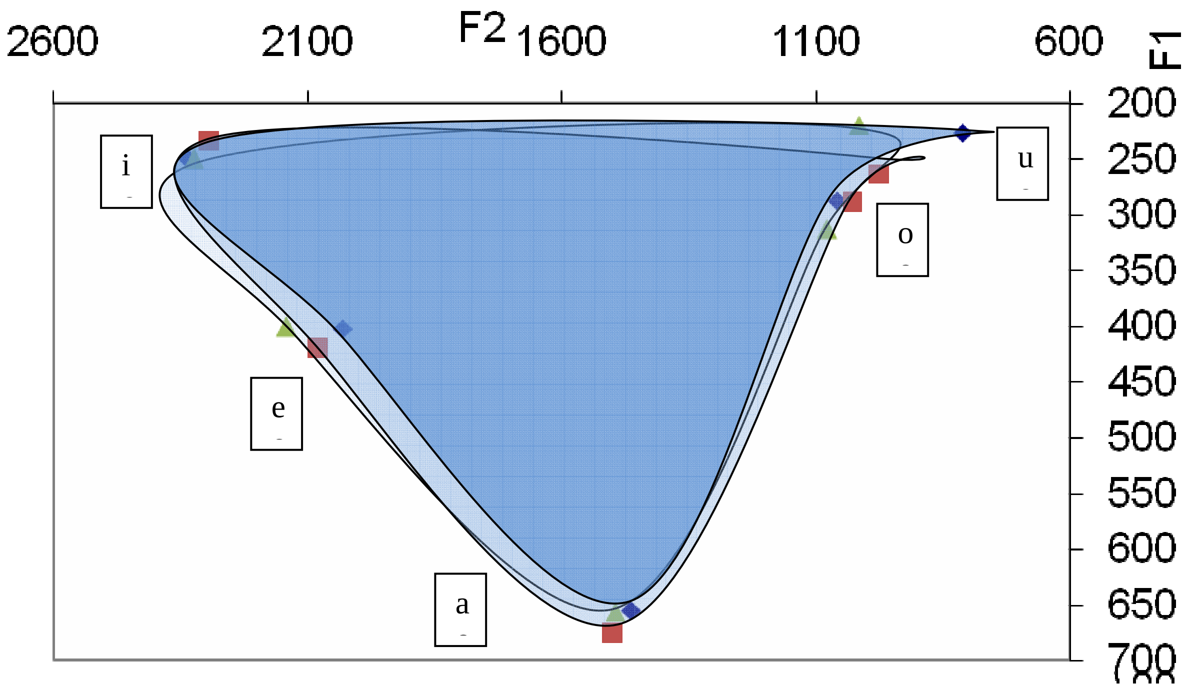


If we wish to cover all types of vowel harmony, we should also consider ATR harmony. Majang is a Nilo-Saharan language spoken in Ethiopia. It has 9 vowels with -ATR harmony. If the theory is right, we might expect -ATR vowels to resist reduction, while +ATR vowels are free to reduce. Unfortunately, in this language, neither set of vowels reduce significantly. So we would need another explanation as to why the reduction is blocked here. One argument would be that in a system with 9 or more vowels, there is just too much precision needed for there to be room for a great deal of reduction. The problem with this argument is that we cannot then say that the standard reduction is undershoot as this should then turn up in short vowels in every language without harmony. A second argument would be that +ATR and –ATR are both spreading. In other words, the tongue root is set either as 'advanced' or 'retracted' for the whole word and neither position is 'neutral'. This is possible, but it is unconventional in most descriptions of ATR spreading. For a full picture of what happens in ATR harmony, we would need to consider several languages. There is room for further research here.

(17) *F1 and F2 for Majang -ATR vowels (recordings: Andreas Joswig)*

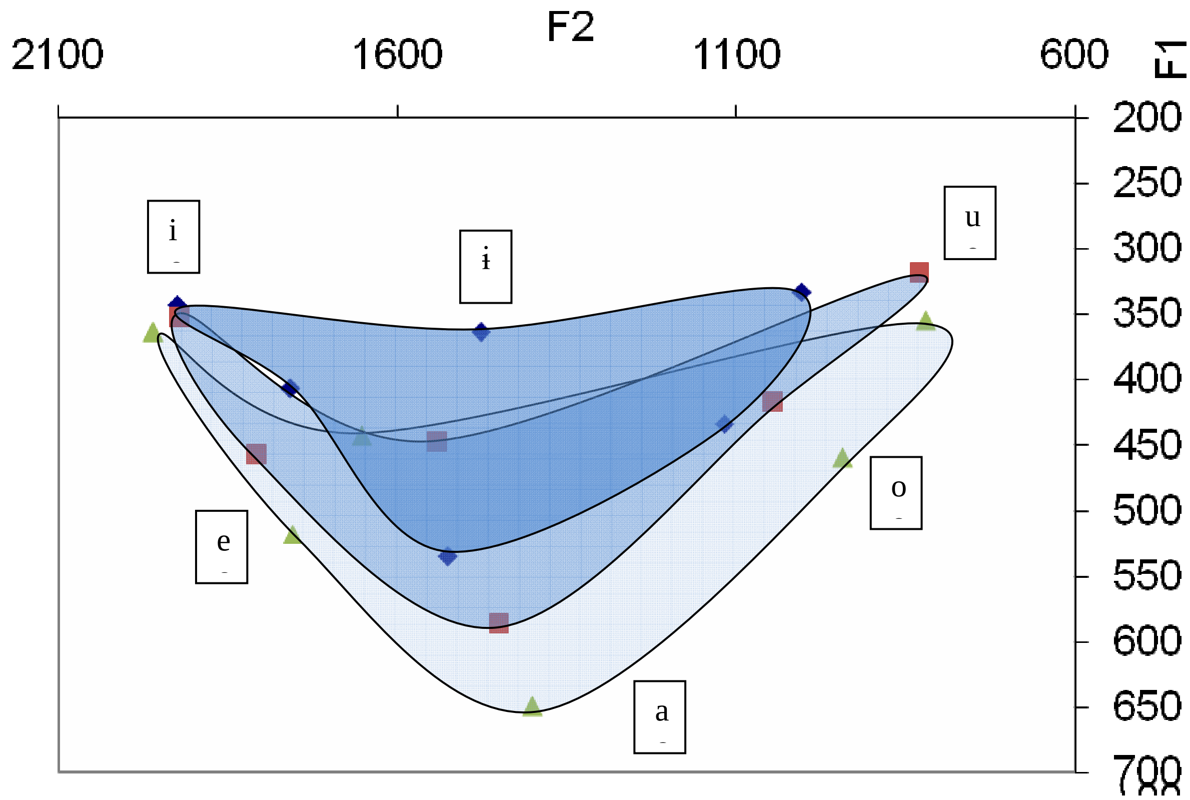


(18) *F1 and F2 for Majang +ATR vowels according to duration*



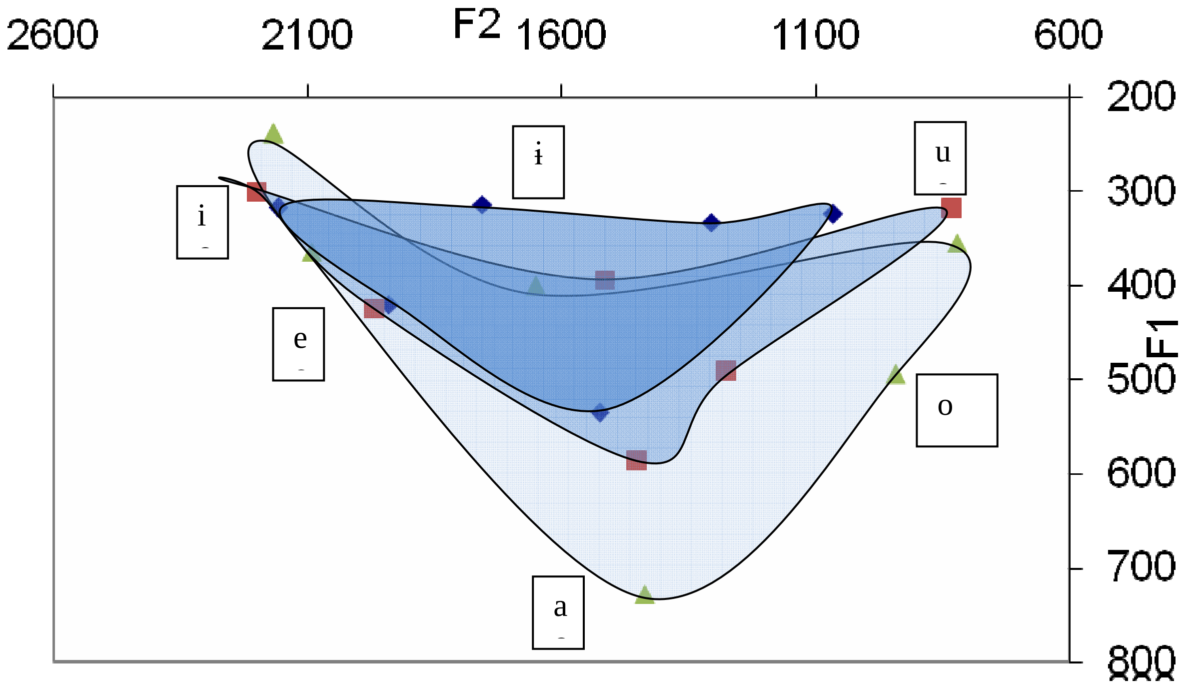
Gumuz is another Nilo-Saharan language spoken in Ethiopia. Gumuz also provides a challenge to the theory because there is no complete vowel harmony, although it may be in the process of being developed. The analysis of Gumuz is in early stages so there are differences of opinion about how many vowels there are. In my investigation from recordings, there appeared to be 6 vowels that were reasonably clear. These are shown below. We look first at vowels across the language from a recorded text. The next graph shows us that in general there is reduction in both axes, although there also appears to be a little fronting which may be slowing down the reduction of the front high vowel.

(19) *F1 and F2 for Gumuz vowels (recordings: Colleen Ahland)*



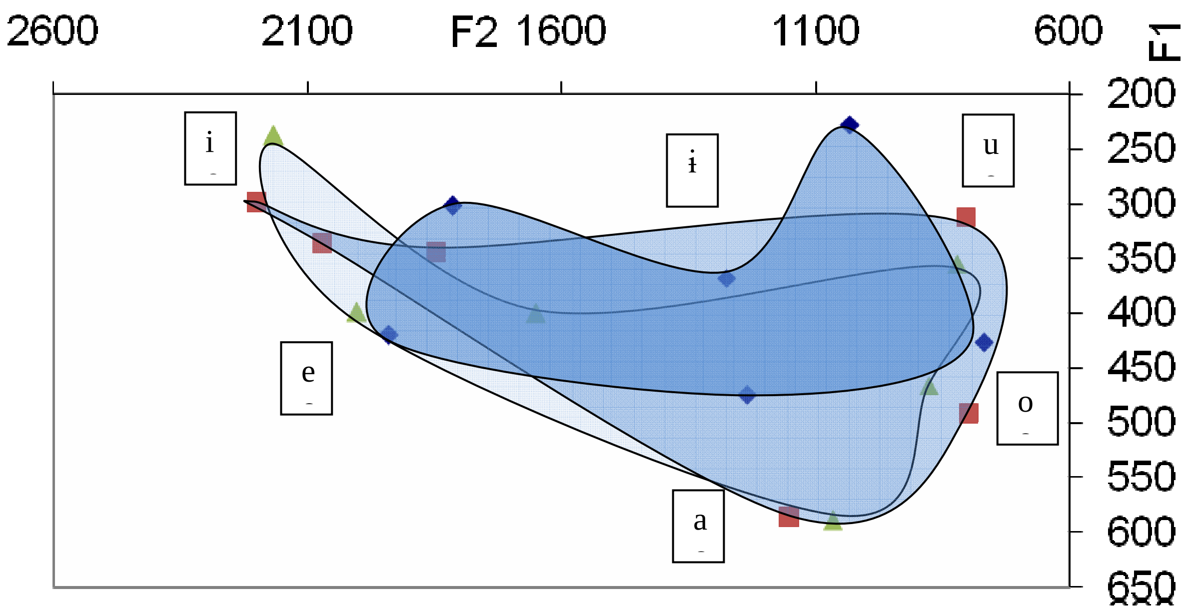
Although there is no vowel harmony in Gumuz, the consonants undergo labialisation and palatalisation, and in words where these processes are in evidence, the vowels are affected to a degree even though they do not lose their underlying features completely. We look first at the effect of palatalisation. Each vowel has a tendency to be a little higher and a little fronted. The effect is most evident in short vowels. This implies that the palatalisation is affecting the starting point for the vowel even though it is not changing the target.

(20) *F1 and F2 for Gumuz vowels with palatalisation*



A similar effect occurs for labialisation. The vowels are again produced a little higher than normal, but they are also moved towards the back vowels. Even long vowels are a little affected by this process. If this trend continues, future generations may reinterpret the central vowels as back vowels. If that happens, Gumuz will have developed vowel harmony. At this point in time however, at least for this speaker, the vowels are still distinct and the changes in quality are phonetic rather than phonological. There are very few instances of the short /u/ vowel, so the apparent wide variation in the diagram below is not significant.

(21) *F1 and F2 for Gumuz vowels with labialisation*



In Gumuz, we cannot analyze the effects on the vowels for this speaker as vowel harmony. The vowels clearly do not change their underlying features. But there is a clear phonetic 'pull' which might be in the opposite direction to the underlying features. For example, a [+low] vowel might be in a [+high, -back] palatalisation domain. The domain feature defines the starting point for the vowel, but the articulators still try to reach the low target as [+low] is still associated with the vowel.

The implication of the Gumuz example is that the features must be held at two levels. Underlying vowels carry features which define the target. This target is clearly phonological. While the spreading domains for palatalisation and labialisation appear to carry a feature over the whole domain and part of the effect of these features is to define the starting point for all the vowels in the domain. In languages where vowel harmony takes place, the underlying feature is deleted and replaced by the feature that is spreading. In Gumuz, the underlying features are not deleted and the effect of the spreading is more phonetic than phonological. This is a challenge to some theories because if palatalisation and labialization are defined in terms of [+high] and [+round] or similar features, then apparently opposite features can interact and both play a part. It seems that the spreading feature can then continue to spread beyond the vowel which carried the opposite feature. The question arises as to whether this is a case of crossing association lines, or could it be that the conflicting features are in fact different and on different tiers, such as [+high] with [+low] or [-back] with [+round]? To come to any conclusions, we would need to find more languages like Gumuz. Although Gumuz does not fit neatly into the group of vowel harmony languages which block vowel reduction, it does seem to support the idea that the underlying features on each segment provide the target while the spreading feature provides the starting point.

There is still room for further research into vowel harmony languages. I am in the process of looking further at Finnish and also investigating Hungarian and Turkish. Early results look promising. These languages appear to confirm my claims about vowel reduction. However, more testing is needed before I can publish these results.

In this paper, we have not covered all types of reduction. There are certainly instances of languages where a phonological reduction results in a smaller inventory of vowels in unstressed position, and these vowels may not include schwa. So in Catalan, Bulgarian, Neapolitan Italian and others, the stressed vowel inventory is typically /i, e, a, o, u/ while the unstressed inventory is simply /i, a, u/ (Crosswhite 2001, Harris 2005). The reduction in this case is centrifugal rather than centripetal. It would be interesting to consider the effects of vowel harmony in these languages, but at present this is beyond the scope of this paper.

5 Conclusion

This paper supports the work of Gendrot and Adda-Decker (2006) in that in many languages in the world, there is a pattern of vowel reduction based on the duration of the vowel and both F1 and F2 are affected by this. As Crosswhite (2001) has claimed, the reason for this reduction is undershoot as there is insufficient time to reach the target quality. However, this paper also presents the claim that in languages where there are spreading processes, including vowel harmony, palatalisation and labialisation; the spreading features are associated with the word or stem level rather than the segmental level. This then has an effect on the amount of reduction. F1 and F2 values are not so reduced in the dimension which is affected by the spreading feature. Either the articulators are physically set in a certain starting position for the whole of the domain and do not return to a neutral position, or messages are sent to the articulators ahead of time with the revised starting point for the whole of the spreading domain. In these languages, reduction can still occur for unspecified vowels and vowels that are not in harmony.

This paper also supports, and gives additional evidence for, the claims of Chadicists that in Chadic languages, vowels are generated from one vowel through processes such as palatalisation and labialisation. The processes of palatalisation and labialisation are present in all Chadic languages even if the consonants no longer give evidence for this (in which case the processes may be described as fronting and rounding harmony).

The investigation into other types of vowel harmony has revealed so far that the same principles apply and that whichever feature is spreading, the reduction is blocked in that dimension. Vowels which are not restricted by harmony have much more freedom to reduce to a schwa-like vowel. The data from Gumuz show us that even when vowel harmony is not categorical, there still seems to be a case for saying that processes such as palatalisation and labialisation can affect the starting point for all the vowels in the spreading domain, even if, as in this case, the underlying features remain as targets for each vowel. We have come to this conclusion because short vowels in Gumuz are the most affected by the spreading feature whereas longer vowels retain their target identity more clearly.

In all of the examples we have looked at, reduction seems to come about not so much due to laziness in production as due to the return to a neutral position when a set of instructions has been completed. So the normal pattern if there is no harmony is that each vowel's starting point is the carrier signal, produced by an open vocal tract. The articulators then receive the message concerning the features associated with the vowel and that becomes the target. Whether the target is reached depends on the duration of the vowel, with approximately 80ms required to arrive at the target for non-high vowels. We have seen that the pattern is different when the vowel is within a feature spreading domain. In this case, the feature which is spreading sets a starting point for all of the vowels in the domain. As each vowel is reached, the articulators move as before towards the target, but starting from this predefined position. So short duration vowels will show evidence of the feature which is spreading, while long duration vowels will reach the target as before.

There is plenty of scope for further research. As stated, I hope to have results soon for Hungarian and Turkish, both of which have very interesting harmony systems. Another area of research could be languages such as Catalan where the type of reduction is categorical and centrifugal rather than centripetal. The question is whether vowel harmony affects the quality in these languages. It would also be interesting to see if the same principles could be applied to other types of feature spreading, such as tone. Several tone languages have a kind of 'neutral' tone in the absence of an underlying tone. But research could be done to see if the pitch is different for tone bearing units that carry their own tone as opposed to segments in a domain where tone spreads. However, given the fact that many languages undergo downstep or declination, experiments of this type might be difficult to execute.

So the main conclusions of this paper are that vowel reduction in many languages is caused by undershoot. F1 and F2 are nearer to a central position if there is insufficient time to reach the target. But reduction is resisted when a vowel is associated with a spreading feature. The articulators starting point is not neutral in a harmony domain. In a language with harmony, only unspecified or neutral vowels undergo reduction. If this hypothesis proves to be correct, it could have major implications for the discussion on the binary nature of spreading features. It should be possible to separate cases where both values of a feature are spreading to those where only one value is spreading by looking at the quality of reduced vowels. These data would then make an important contribution into the discussion on the typology of features.

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