

**AN ACOUSTIC AND STATISTICAL ANALYSIS OF SPANISH
MID-VOWEL ALLOPHONES**

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ABSTRACT

In 1918 Navarro Tomás claimed that Spanish mid vowels have open and close allophones. Whilst some acoustic studies have supported these claims, others have not. The conclusions in these studies were subjective since they failed to apply statistical analysis to the acoustic data. Statistical analysis is required to determine whether data with a range of values can be grouped into distinct categories. The present study investigates the production of Spanish /e/ and /o/ in several contexts in which Navarro Tomás claimed open and close allophones would be found. Recordings were made of a male and a female speaker of educated Madrid Spanish, the dialect which Navarro Tomás originally described. First and second formants were measured and statistically analysed. Formant frequencies did not cluster into two groups associated with the contexts in which Navarro Tomás claimed each allophone would occur. Other potential allophones were identified: fronted and retracted allophones for /o/; and close-fronted, central, and open-retracted allophones for /e/.

RESUMEN

En 1918 Navarro Tomás afirmó que había alófonos abiertos y cerrados de las vocales medias de castellano. Aunque los resultados de varios estudios subsiguientes están de acuerdo con la afirmación, otros están en desacuerdo. Las conclusiones de estos estudios son subjetivas porque no analizaron estadísticamente los datos acústicos. Un análisis estadístico es imprescindible para determinar si se pueden asignar datos con una variedad de valores a categorías distintas. El presente estudio investiga la producción de /e/ y /o/ castellano en varios de los contextos en que Navarro Tomás afirmó que había alófonos abiertos y cerrados. Se grabaron las producciones de un hombre y una mujer, hablantes de un dialecto madrileño educado, el dialecto que Navarro Tomás describió. Se midió y analizó estadísticamente el primer y el segundo formante de las vocales. Las frecuencias de los formantes no se apiñaron en dos grupos asociados con los contextos en que Navarro Tomás afirmó aparecía cada alófono. Se identificaron otros alófonos potenciales: anterior y posterior para /o/; y anterior-cerrado, central, y posterior-abierto para /e/.

1. INTRODUCTION

During approximately the last one hundred years it has often been repeated that there are open and close allophones of the Spanish mid vowels /e/ and /o/. The authority quoted is invariably Navarro Tomás ([1918] 1965: §51, 52, 58, 59). He claimed that there were open and close allophones of all four non-low vowels /i e o u/ and fronted, central and retracted allophones of the low vowel /a/, e.g., [ˈbj̞na] *viña* ‘vineyard’ – [ˈr̞j̞ko] *rico* ‘rich’, [ˈp̞ɛ̞ɲa] *peña* ‘rock’ – [ˈp̞ɛ̞ro] *perro* ‘dog’, [ˈm̞o̞ða] *moda* ‘fashion’ – [ˈr̞o̞sa] *rosa* ‘rose’, [ˈk̞a̞ɲa] *caña* ‘reed’ – [ˈk̞a̞ro] *caro* ‘expensive’ – [ˈb̞axo] *bajo* ‘low’ (Navarro Tomás 1965: §41–63).¹ He further claimed that the difference between the mid-vowel allophones (hereafter [e]–[ɛ] and [o]–[ɔ]) was greater than the difference between the high-vowel allophones. The distributions of the mid-vowel allophones posited by Navarro Tomás (1965) are summarised in Table 1. These distributions are extremely complex – D’Introno, Teso, & Weston (1995) dedicated 32 pages to the task of expressing the relevant contexts in phonological rewrite rules.

Navarro Tomás (1916) published radiographic and palatographic data from his own vowel productions. He spoke using a cultivated Madrid accent and had to hold the vowels for approximately 600 ms in order to obtain the radiographic images. He measured the aperture of the mandibles and the height of the top of the tongue relative to the bottom of the upper molars. For the underlined vowels in the words *tener* /teˈner/ ‘have’, *aquella* /aˈkeʎa/ ‘that one’, *olor* /oˈlor/ ‘smell’, and *olla* /ˈoʎa/ ‘pot’, the vowels preceding /r/ were more open than the vowels preceding /k/. These results are predictable from coarticulation effects: the dorsum of the tongue must rise to make contact with the palate in order to articulate the palatal lateral /k/, resulting in a closer vowel; and the dorsum of the tongue must lower as the tip rises in order to articulate the apicoalveolar trill /r/, resulting in a more open vowel.

The majority of studies relating to the putative mid-vowel allophones have made use of acoustic data. In the acoustic analysis of vowels, a high first formant (F1) corresponds with the traditional articulatory/auditory term *open*, and a high second formant (F2) corresponds to the traditional term *fronted*, i.e., there is a positive correlation between F1 and vowel openness, and between F2 and vowel frontness.

¹ He also claimed that there were additional relaxed allophones for vowels with neither primary nor secondary stress.

This allows the F1 and F2 values to be plotted in such a way as to correspond to the position of vowels on the traditional vowel quadrilateral.²

| <i>/e/</i> | | <i>/o/</i> | |
|--|--|--|--|
| CLOSE [e] | OPEN [ɛ] | CLOSE [o] | OPEN [ɔ] |
| In an open syllable | Adjacent to /r/ (but not in a syllable closed by /m n θ d s/) | In an open syllable (but not between /a/ and /r/ or /l/) | Adjacent to /r/ |
| In a syllable closed by /m n θ d s/ | Preceding /x/ | | Preceding /x/ |
| | In the diphthong /ej/ | | In the diphthong /oj/ |
| | In a syllable closed by any consonant other than /m n θ d s/ | | In a syllable closed by any consonant |
| | | | Between /a/ and /r/ or /l/ |

Table 1. *Contexts, according to Navarro Tomás (1965), for open and close allophones of /e/ and /o/ in syllables with primary or secondary stress.*

Alarcos Llorach (1965) published spectral data on the putative mid vowel allophones, but only included F2 values. He concluded that there were fronted and retracted allophones of the mid vowels; however, he did not explain the methodology whereby he obtained his measurements, nor did he apply a statistical analysis to the data.

Cárdenas (1960) analysed the vowels of a Colombian Spanish speaker and of a US Spanish speaker with a Mexican family background. The participants read

² This type of F1–F2 plot may first have been drawn by Essner (1947) or Joos (1948: §2.3) following the invention of the Acoustic Spectrograph, although the general concept of the relationship between tongue position and acoustic resonance was not new (see Chiba and Kajiyama 1941: ch. 5; and Nearey 1978: §1.2).

sentences containing words in which the mid vowels occurred in different contexts. The majority of words were spoken only once. On the basis of F1 measurements, Cárdenas concluded that the vowels were not subject to consistent allophonic variation due to phonetic context. In a reply to Cárdenas (1960), Navarro Tomás (1960) stated that in his initial observations on vowel allophones he had been describing an educated Peninsular accent, and these observations were not therefore contradicted by Cárdenas's findings for American accents. He also disputed Cárdenas's analysis of the data, claiming that in many cases the F1 measurements were in accord with those predicted for the respective allophones. He speculated that the failure of Cárdenas to find open allophones preceding /r/ may have been due to /r/ being pronounced as an approximant³ rather than a trill.

Skelton (1969) presented data from F1 and F2 measurements of the vowels in 1700 sentences produced by 20 speakers from various regions of Spain and America. His data supported the claims of Navarro Tomás (1965). For stressed /e/, only putative close allophones had F1–F2 values that overlapped the F1–F2 values of stressed /i/ (and no putative close allophones of /i/ occurred in the overlapping area). For stressed /o/ with F1 values below the overall F1 mean for /o/, there were three times as many instances of putative close allophones as putative open allophones. Instances of stressed /o/ with the lowest F1 values also corresponded exclusively to putative close allophones.

Martínez Celdrán (1994: 289–301) measured F1 and F2 for mid vowels produced by male speakers. He separated the resulting measurements into close, mid, and open groups. The open /e/ group corresponded 59% with the open allophones of Navarro Tomás (1965), and the close /e/ group corresponded 70% with the close allophones. For open and close /o/ the correspondences were 52% and 56% respectively. Martínez Celdrán did not give details of his methodology, nor did he apply a statistical analysis to the data. After studying his own and other researchers' data, Martínez Celdrán (1994: 301) concluded that:

A la vista de estos datos no es posible afirmar que la diferencia entre abiertas y cerradas sea un hecho sistemático en castellano. La variabilidad no depende tanto de los contextos como de la multiplicidad de circunstancias de habla. [In view of these data,

³ Navarro Tomás uses the Spanish term *fricativa*. It is not clear in this context whether this is best translated as 'fricative' or 'approximant' (see Martínez Celdrán, 1984).

it is not possible to affirm that the difference between open and close [allophones] is a systematic reality in Spanish. The variability does not depend so much on [phonetic] context as on the multiplicity of circumstances of speech [dialects, idiolects, etc.]].

The present paper reports on a study which investigates the production of /e/ and /o/ in several contexts in which Navarro Tomás (1965) claimed that there would be open and close allophones. The two participants in the study were educated professionals who were speakers of Madrid Spanish and thus corresponded to the educated Peninsular accent that Navarro Tomás first described.⁴ The first and second formant values of the speakers' vowels were measured and the results subjected to a statistical analysis. The studies cited above were methodologically flawed since they did not include a statistical analysis of the data. Visual inspection or simple counts do not provide a rigorous test as to whether a set of data points reflect a conflation of two or more distinct distributions from separate categories, or whether the distribution is that of a single homogeneous category. A statistical analysis provides a quantifiable measure of the likelihood that the F1 and F2 measures come from two separate allophones.

2. METHODOLOGY

2.1. Participants

There were two participants in the study, one male and one female. Both were highly educated professionals (a lawyer and a university professor) from Madrid. The male was 40 years old and had lived in Madrid for all but a few months of his life. He was able to speak a little English. The female was 30 years old and had lived until age 25 in Madrid. She had also lived in North America and was able to speak English, German, and Galician. Both participants passed a hearing screen: ability to hear a pure sinusoidal wave at 30 dB between 250 and 4000 Hz.

⁴ Given that over 80 years have passed since Navarro Tomás collected his data, it must be recognised that the participants in the present study do not speak with exactly the same accent: diachronic changes such as the switch to *yeísmo* ([χ]→[j]) have occurred.

2.2. Stimuli

Words were chosen which exemplified contexts in which Navarro Tomás (1965) claimed open and close allophones of /e/ and /o/ vowels would occur. The words were chosen in pairs so as to provide an equal number of putative open and close allophones. All the words were real Spanish words (although not necessarily common words), and the vowels of interest were in stressed positions. A full set of words is given in Tables 2 and 3 (subsequent reference to the word contexts will be made using phonemic transcriptions in the International Phonetic Alphabet with syllable boundaries marked where pertinent).

The words were presented to the participants in written form in the carrier sentence *Pues ___ se ha dicho* ‘Well she/he said ___ to him/herself’. A fixed carrier sentence was used to ensure that any allophonic variation in the vowels would be due to the phonetic context provided by the word, and not due to differences in the sentence as a whole. There were a total of 24 sentences which were presented 10 times in random order.

| WORDS CONTAINING PUTATIVE /e/ ALLOPHONES | | | | | |
|--|--|---------------------------|------------------------|---|--------------------------|
| [ɛ] | | | [e] | | |
| Contexts | | | Contexts | | |
| Adjacent to /r/ | <i>p<u>e</u>rra</i> ‘bitch’ | / ^h pera/ | Not adjacent to /r/ | <i>p<u>e</u>ra</i> ‘pear’ | / ^h pera/ |
| | <i>r<u>e</u>ta</i> ‘she/he challenges’ | / ^h reta/ | | <i>p<u>e</u>ta</i> ‘joint’ (colloquial) | / ^h peta/ |
| Preceding /x/ | <i>g<u>e</u></i> ‘axis’ | / ^h exe/ | Not preceding /x/ | <i>g<u>e</u></i> ‘that’ | / ^h ese/ |
| Syllable closed by /l/ | <i>sg<u>l</u></i> ‘pasture’ (colloquial) | / ^h sel/ | Syllable closed by /d/ | <i>sg<u>d</u></i> ‘thirst’ | / ^h sed/ |
| Syllable closed by /p/ | <i>con<u>ce</u>pto</i> ‘concept’ | /kon ^h θep.to/ | Open syllable | <i>con <u>ce</u>po</i> ‘with bait’ | /kon ^h θe.po/ |
| Syllable closed by /k/ | <i>sg<u>ct</u>a</i> ‘sect’ | / ^h sek.ta/ | Open syllable | <i>sg<u>ca</u></i> ‘dry’ | / ^h se.ka/ |

Table 2. Words read by the speakers in the present study exemplifying phonetics contexts in which Navarro Tomás (1965) claimed that open and close allophones of /e/ occur.

| WORDS CONTAINING PUTATIVE /o/ ALLOPHONES | | | | | |
|--|-----------------------------|------------------------|------------------------|-------------------------------------|-----------------------|
| [ɔ] | | | [o] | | |
| Contexts | | | Contexts | | |
| Adjacent to /r/ | <i>porra</i> 'truncheon' | / ^l pɔrɑ/ | Not adjacent to /r/ | <i>pora</i> 'for' (antiquated) | / ^l pɔrɑ/ |
| | <i>rota</i> 'rattan' | / ^l rɔtɑ/ | | <i>pota</i> 'crown of anchor' | / ^l pɔtɑ/ |
| Preceding /x/ | <i>ojo</i> 'eye' | / ^l oxo/ | Not preceding /x/ | <i>oso</i> 'bear' | / ^l oso/ |
| Syllable closed by /θ/ | <i>vɔz</i> 'voice' | / ^l bɔθ/ | Open syllable | <i>bɔzo</i> 'fluff on upper lip' | / ^l bɔ.θo/ |
| Syllable closed by /p/ | <i>copto</i> 'Copt' | / ^l kɔp.to/ | Open syllable | <i>copo</i> 'flake' | / ^l kɔ.po/ |
| Syllable closed by /k/ | <i>docta</i> 'erudite' | / ^l dɔk.ta/ | Open syllable | <i>dɔca</i> 'Chilean fig' | / ^l do.ka/ |

Table 3. Words read by the speakers in the present study exemplifying phonetics contexts in which Navarro Tomás (1965) claimed that open and close allophones of /o/ occur.

2.3. Recording

The recording took place in a soundproofed room. The participants read the list of randomly ordered sentences, and were recorded using a Sony MZS-R5ST Mini Disc recorder and a Sony ECM-MS907 microphone. The recordings were transferred to computer via a Roland ED UA-30 interface and saved as 22.05 kHz 16 bit sound files using Cool Edit Pro LE (Johnston, 1999).

2.4. Acoustic analysis

Acoustic analysis was performed using Praat 3.9 (Boersma & Weenink, 2000). The beginning and end of each vowel of interest was manually marked and the vowel labelled. An automated process then measured F1 and F2 at the centre of each

vowel⁵ using the Burg LPC autocorrelated tracking algorithm. The automated process also displayed pictures of the spectrogram with the formant track overlaid to allow the investigator to confirm that the tracking algorithm was producing appropriate results and to take manual measurements or adjust the algorithm parameters if necessary. Parameters used for the tracking algorithm were: step size 10 ms; window size 35 ms; maximum formant 5500 Hz; maximum number of formants were 4 for the female speaker's /e/, 5 for the female speaker's /o/ and male speaker's /e/, and 6 for the male speaker's /o/. F1 and F2 values were recorded in mel, a scale which has a linear relationship with human frequency perception (see Harrington & Cassidy, 1999: 18–19).

2.5. Statistical analyses

Two statistical procedures were applied to the F1 and F2 data: the first, *cluster analysis* (Romesburg 1984; SPSS 1999), was used to determine whether the vowels clustered in groups that corresponded to their contexts; the second, *discriminant analysis* (Tatsuoka 1970; Klecka 1980; SPSS 1999; Brown & Wicker 2000; Stevens 2002), was used to determine the degree of differentiation between groups of contexts identified via cluster analysis. If distinct allophones exist, then F1–F2 values from vowels belonging to different allophones are expected to cluster into different groups and these groups are expected to account for the majority of the variability in the F1–F2 values. Statistical analyses were carried out using SPSS software (SPSS, 1999).

As the first step in hierarchical cluster analysis, the distance from each case to every other case is calculated. In the present study, this was the distance from each instance of a vowel to every other instance of that vowel. The distances were measured as squared Euclidian distances on a two-dimensional plane in which one dimension was standardised F1 values and the other standardised F2 values. Since F2 frequencies are higher than F1 frequencies and may therefore have greater absolute variance, use of unstandardised values may result in F2 values having a greater weight in the distance measurements than F1. Standardisation results in both variables having equal weight.⁶ The F1 and F2 values in the present study

⁵ Measuring formants at the centre of the vowels was consistent with earlier acoustic studies. This also ensured that any allophonic variation detected would be substantial in that it would not be due merely to minor coarticulatory effects at the periphery of the vowels.

were standardised to z scores (mean of 0 and standard deviation of 1). As the second step in cluster analysis, the two cases which are closest to each other are clustered (i.e., grouped together). As the third step, distances from the new cluster to every other case are then calculated. In the present study these distances were measured using the average linkage method (a.k.a. unweighted pair-group method using arithmetic averages / between-groups linkage method) in which the distance to a case outside the cluster is calculated as the mean of its distance to each case within the cluster. Steps two and three are then repeated successively joining the closest case and case / case and cluster / cluster and cluster until a single cluster is formed containing all cases and other clusters. By keeping track of the order in which clusters are formed and the distance between cases/clusters when they are joined, a dendrogram can be drawn representing the clustering of cases and sub clusters. A sample dendrogram is shown in Figure 1. If the cases are to be divided into two, three, four clusters, etc. the dendrogram should be split at a point where a horizontal line drawn across the dendrogram would bisect two, three, four, branches, etc..

Scatterplots (see Figures 3, 6, 10, 11) of each case (each instance of a vowel) were plotted in the F1–F2 space. Each case was coded for original phonetic context and cluster membership.⁷ Up to six clusters were initially plotted. The investigator visually inspected the scatterplots and dendrograms to determine whether clusters corresponded with phonetic contexts. If vowels from a particular context were spread over two or more clusters, then the investigator moved up the cluster hierarchy to determine whether vowels from this context might be contained within a hierarchically superior cluster. A cluster was determined to correspond to a potential allophone if the vast majority of vowels from each of one or more contexts were contained within this cluster, and there was no context providing vowels which were relatively evenly spread between this cluster and one or more other clusters. A potential allophone was defined by the group of contexts from which the vast majority of cases fell within the type of cluster just described, rather than by the actual cases included in the cluster itself. An additional criterion for determining potential allophones was that the cluster hierarchy be split at such a place whereby all of the resulting clusters met the above criteria for

⁶ It may be that one of F1 or F2 has greater weight in human perception of vowels and on Spanish listeners' perception of Spanish vowels in particular; however, this would have to be determined via perceptual experiments on established categories. Since it is not clear what weighting would be appropriate at this stage, a default of equal weight was used.

⁷ Contexts were originally coded by colour and clusters by shape. In the figures below, loops have been drawn around clusters, and contexts are coded by shape and fill.

correspondence to potential allophones. See the results for the male speaker's /o/ in section 3.1 below for an example of this process.

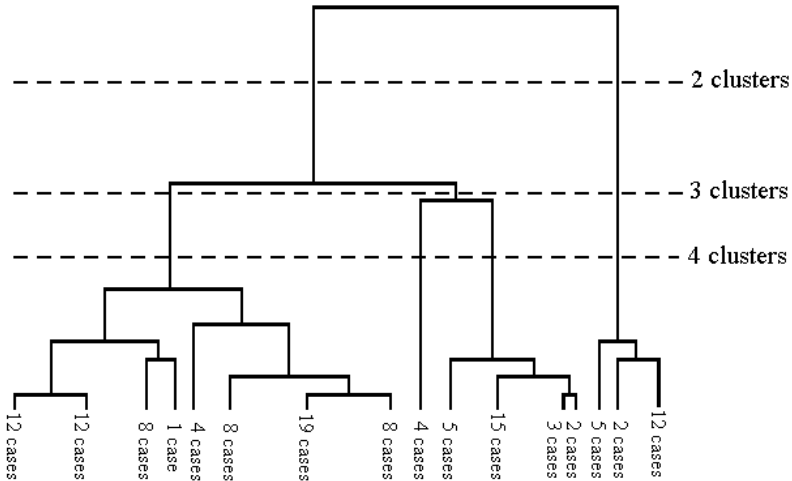


Figure 1. A partial dendrogram produced by a cluster analysis (cluster analysis carried out on the /e/ productions of the female speaker in the present study). The dendrogram has been truncated; a complete dendrogram would include the initial linkages of each individual case. The relative heights of the linkages between clusters and cases represent the relative distance between those clusters and cases, i.e. clusters joined lower down in the diagram are closer to each other than clusters joined higher in the diagram. The dashed horizontal lines represent places where the dendrogram could be split in order to provide two, three, or four clusters.

Once potential allophones had been established via cluster analysis, a discriminant analysis was carried out to quantify the degree of separation between these potential allophones. If cases described by multiple predictor variables (in this case F1 and F2) belong to two pre-established groups, the discriminant analysis produces a discriminant function, a particular combination of variables, which maximises the separation of the cases belonging to each group. Each group will have its own distribution on the line described by the discriminant function. A case

is classified by measuring its distance on the discriminant function line from the centroids (or means) of each group and assigning it to the group to whose centroid it is closest (Mahalanobis distances are used). A category boundary occurs at the point on the discrimination function line which is equidistant between the two centroids. If there are three groups then there will usually be two discriminant functions (the second perpendicular to the first) and cases will be classified by their proximity to group centroids on a 2 dimensional plane instead of a one dimensional line. The situation is somewhat complicated if there is a difference in frequency of occurrence of each group in the population. Cases are classified based on probability of group membership calculated according to Mahalanobis distance from group centroids, but the posterior probabilities produced by the model are adjusted by prior probabilities based on the number of cases in each group in the sample. Figure 4 shows a graphical example of the line described by the discriminant function, the probability of membership in each allophone adjusted for prior probabilities, and the category boundary for classification of allophones. One test of the success of the discriminant model is to determine the number of cases which are correctly classified according to their original group membership.

A statistic of particular interest in the present study is Wilks's lambda, which is the ratio of the within-group variability to the total variability. A Wilks's lambda value close to 0 indicates that the variability in the data is primarily due to differences between the groups, whereas a value close to 1 indicates that the variability is primarily due to within group differences. That is, if the two groups were completely distinct then the Wilks's lambda value would be almost 0, but if there were no difference between the groups then the Wilks's lambda value would be almost 1 (e.g., if the two groups consisted of two random samples from a single population and therefore have identical expected values for their means and variances). Random sampling differences will usually preclude Wilks's lambda values of exactly 0 or 1. In the present study, if the potential allophones determined by cluster analysis result in a high Wilks's lambda value, then this would indicate that differences between the groups are probably due to random variability rather than consistent allophonic differences. Wilks's lambda can be calculated for individual discriminant functions or for the whole set of discriminant functions used in the analysis; values quoted below refer to the latter.

In the discriminant analyses in the present study, F1 and F2 were entered simultaneously into the model as predictor variables, potential allophones suggested by cluster analysis were used as grouping variables, and prior probabilities were calculated according to the number of cases in each group.

3. RESULTS AND DISCUSSION

3.1. Allophones of /o/

Figure 2 shows the F1–F2 distribution of /o/ vowels produced by the male speaker. The vowels are coded according to Navarro Tomás's (1965) contexts for open and close allophones. A visual inspection of Figure 2 suggests that the vowels do not fall into the two putative allophones. This was supported by a discriminant analysis: Wilks's Lambda was .979, close to 1 indicating that the two putative allophone groups are likely taken at random from a single population. Only 55.9% of cases were correctly classified by the discriminant analysis model.

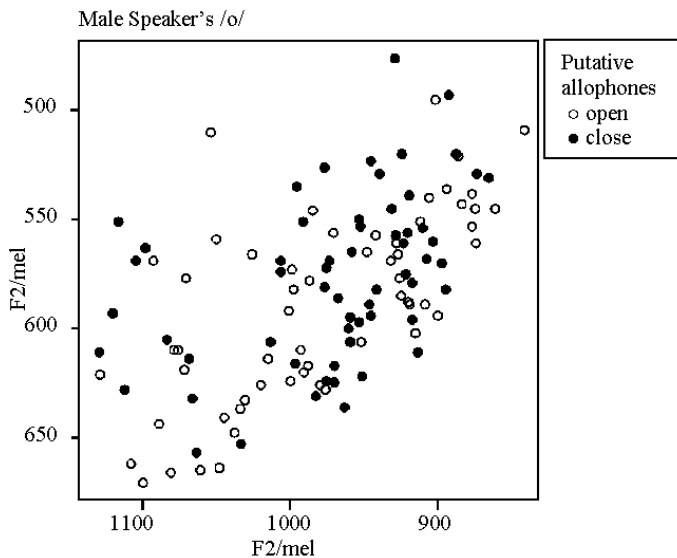


Figure 2. *Male speaker's /o/ productions coded according to contexts in which Navarro Tomás claimed open and close allophones occur.*

The largest four clusters resulting from cluster analysis performed on the male speaker's /o/ results are shown in Figure 3. The first two clusters (enclosed by the thickest lines) corresponded with potential allophones: one cluster contained all

instances of vowels from the contexts /^hrota/ and /^hdo.ka/, and all but two instances from /^hdok.ta/. The other cluster contained all instances of vowels from all other contexts with the exception of one instance each from /^hboθ/ and /^hbo.θo/. Further division did not result in clusters corresponding to potential allophones: A division into three clusters resulted in instances of /^hdo.ka/ and /^hdok.ta/ being spread across two clusters. A division into four clusters resulted in instances from multiple contexts being spread across two clusters. Two potential allophones were therefore used as grouping variables in the discriminant analysis: a potential fronted allophone consisted of the contexts /^hrota/, /^hdo.ka/, and /^hdok.ta/; and a potential retracted allophone consisted of the remainder of the contexts. The discriminant analysis resulted in a low Wilks's lambda of .337, indicating that the two potential allophones were relatively distinct. All members of the potential retracted allophone were correctly identified and only one member of the potential fronted allophone was incorrectly identified (see Figure 4).

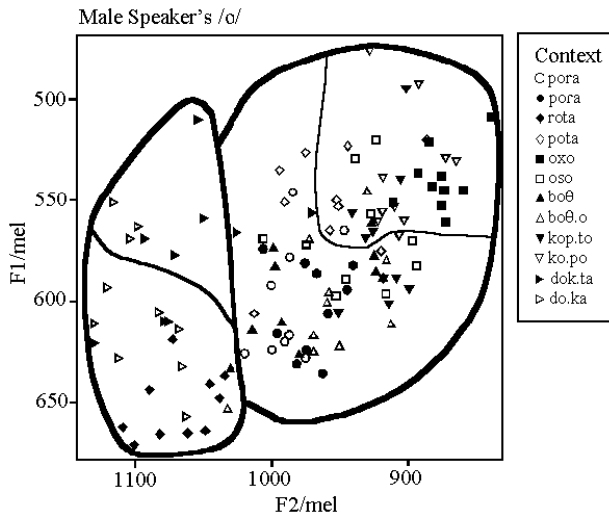


Figure 3. Largest four clusters resulting from a cluster analysis performed on male speaker's /o/ productions. The thickest lines enclose the first two clusters, and thinner lines indicate the partitioning of these clusters into subclusters.

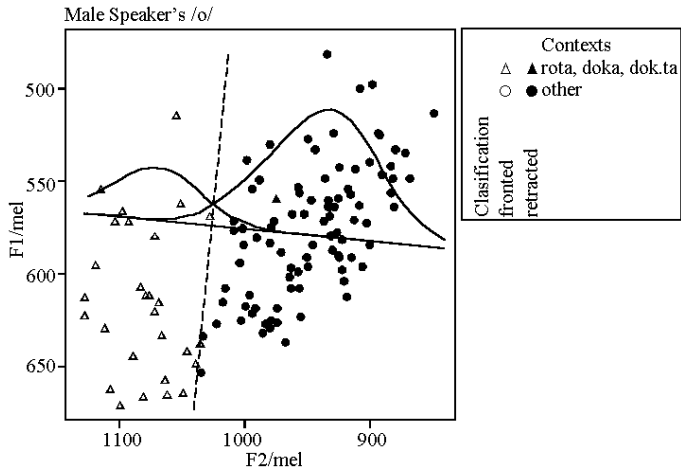


Figure 4. Classification into potential fronted and retracted allophones from a discriminant analysis performed on male speaker's /o/ productions. Overlaid lines represent the discriminant function (solid straight line), probability of membership in each allophone adjusted for prior probabilities based on number of cases in group (curved lines), and categorical boundary between allophones (dashed line).

Figure 5 shows the F1–F2 distribution of /o/ vowels produced by the female speaker coded according to Navarro Tomás's (1965) contexts for open and close allophones. This division was more successful than for the male speaker: 70.8% of cases were correctly classified by the discriminant analysis. However, Wilks's lambda was .779, relatively close to 1, indicating considerable overlap between the two putative allophones.

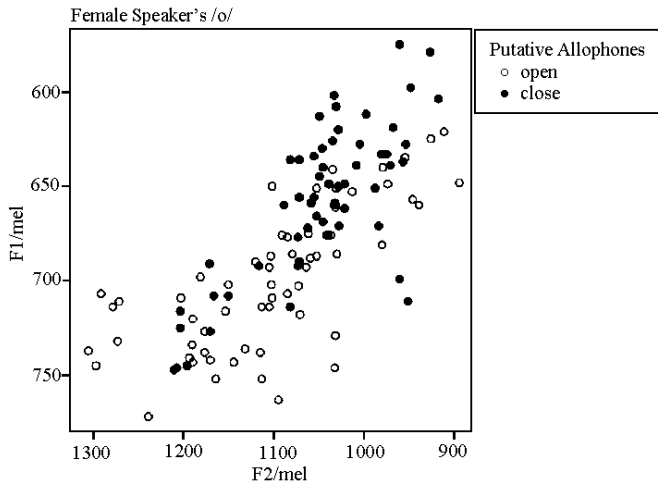


Figure 5. Female speaker's /o/ productions coded according to contexts in which Navarro Tomás claimed open and close allophones occur.

The largest four clusters resulting from the cluster analysis performed on the female speaker's /o/ are shown in Figure 6. None of the four largest clusters were ideal candidates for correspondence with potential allophones. The first two clusters consisted of /^lrota/, /^ldo.ka/, /^ldok.ta/, and /^lkop.to/ in one cluster, and the remainder of contexts in the other cluster, except for /pora/ which was spread relatively evenly across the two clusters (6 instances in the former cluster and 4 in the latter). Two discriminant analyses were conducted, one with /pora/ included in the potential allophone corresponding to the former cluster, and one with it in the potential allophone corresponding to the latter cluster. Visual inspection of Figure 6 suggests that if /pora/ is excluded from the first potential allophone, then /^lkop.to/ would also be a candidate for exclusion. The latter pair of potential allophones (/rota/, /do.ka/, and /dok.ta/, versus the remainder of contexts) also match the potential allophones identified for the male speaker. A third discriminant analysis was conducted using this pair of potential allophones. Table 4 gives the Wilks's lambdas and the number of incorrectly identified cases for each of the three discriminant analyses. All three analyses resulted in similar low values for

Wilks's lambda but the grouping in the final analysis was considered better since it resulted in a lower number of incorrectly identified cases. The classification results for this analysis are shown in Figure 7.

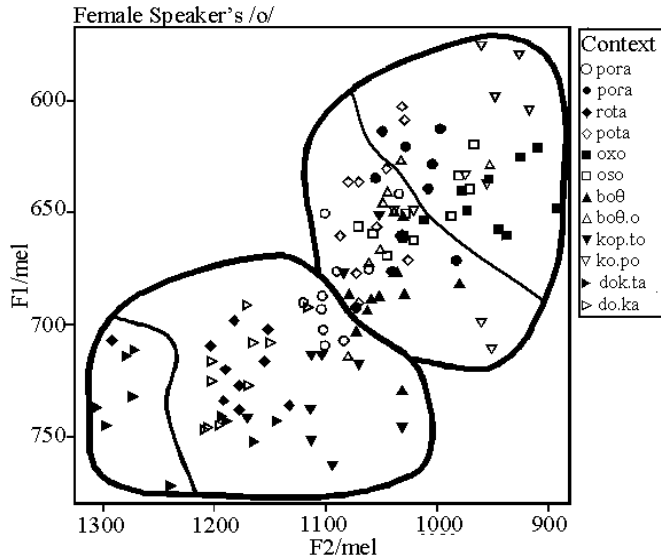


Figure 6. Largest four clusters resulting from a cluster analysis performed on female speaker's /o/ productions.

| ALLOPHONE GROUP | WILKS'S LAMBDA | NUMBER OF CASES INCORRECTLY CLASSIFIED |
|-----------------------------------|----------------|--|
| rota, dok.ta, do.ka, kop.to, pora | 0.352 | 8 (6.7%) |
| rota, dok.ta, do.ka, kop.to | 0.337 | 8 (6.7%) |
| rota, dok.ta, do.ka | 0.358 | 2 (1.7%) |

Table 4. Wilks's lambda and number of cases incorrectly classified from discriminant analyses conducted on the female speaker's /o/ productions. Grouping variables consisted of the contexts listed under "allophone group" versus the remainder of contexts.

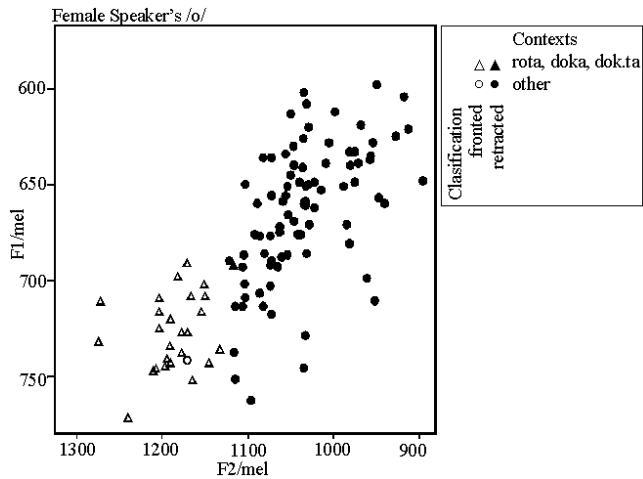


Figure 7. Classification into potential fronted and retracted allophones from a discriminant analysis performed on female speaker's /o/ productions

In summary, the F1–F2 values at the centre of the speakers' /o/ were not consistent with open and close allophones in the contexts claimed by Navarro Tomás (1965). Cluster analyses and discriminant analyses suggested that the speakers' /o/ could instead be grouped into fronted and retracted allophones. The contexts for the fronted allophone, /*rota*/, /*do.ka*/, and /*dok.ta*/ differ from the contexts for the retracted allophone in that in the former the vowel is preceded by a coronal consonant, /*r*/ (apicoalveolar trill) or /*d*/ (dental plosive). This is consistent with an articulatory basis for the fronted allophone: the raised tongue tip required to articulate the consonant results in a relatively advanced tongue position continuing through to the central portion of the vowel.

3.2. Allophones of /e/

Figures 8 and 9 show the F1–F2 distribution of /e/ vowels produced by the male and female speaker respectively. The vowels are coded according to Navarro Tomás's (1965) contexts for open and close allophones. In discriminant analyses, 69.2% of the male speakers' vowels, and 79.2% of the female speakers' vowels were correctly classified. Wilks's lambda values were .797 and .704 for the male

and female speaker respectively. These values are relatively close to 1 indicating considerable overlap between the putative allophones.

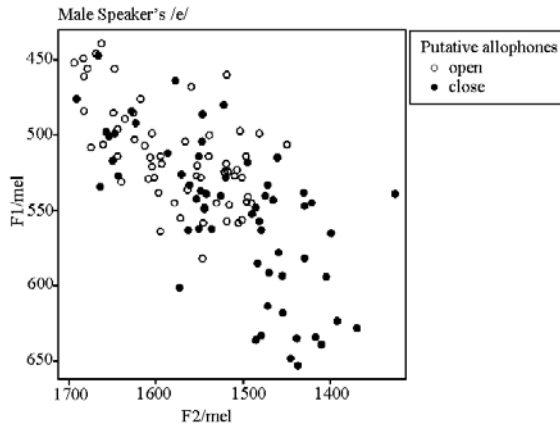


Figure 8. Male speaker's /e/ productions coded according to contexts in which Navarro Tomás claimed open and close allophones occur.

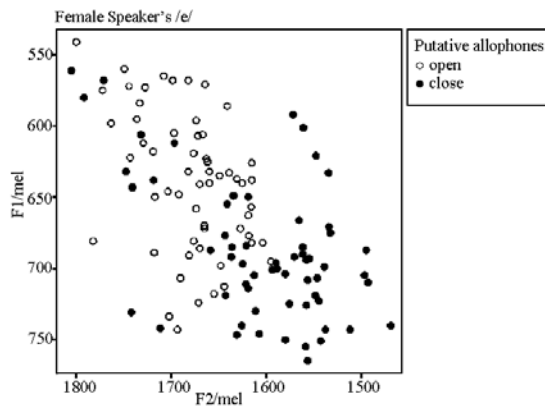


Figure 9. Female speaker's /e/ productions coded according to contexts in which Navarro Tomás claimed open and close allophones occur.

As can be seen in Figures 10 and 11, the cluster analyses on the male and female speakers' /e/ productions did not result in clusters which were good candidates for correspondence with potential allophones. A number of discriminant analyses were conducted using different groups of contexts as potential allophones. The results of these analyses are summarised in Table 5.

| ALLOPHONE GROUPS | MALE SPEAKER | | | FEMALE SPEAKER | | |
|--|----------------|--|---------|----------------|--|---------|
| | WILKS'S LAMBDA | NUMBER OF CASES INCORRECTLY CLASSIFIED | | WILKS'S LAMBDA | NUMBER OF CASES INCORRECTLY CLASSIFIED | |
| (pera,reta, konθep.to) | 0.452 | 7 | (5.8%) | | | |
| (pera,reta, konθep.to) (ese,exe,peta) | 0.184 | 11 | (9.2%) | | | |
| (pera,reta) (ese,exe,peta) | 0.248 | 13 | (10.8%) | 0.259 | 11 | (9.2%) |
| (pera,reta) (ese,exe) | 0.319 | 19 | (15.8%) | 0.320 | 15 | (12.5%) |
| (ese,exe,peta) | | | | 0.471 | 7 | (5.8%) |

Table 5. Wilks's lambda and number of cases incorrectly classified from discriminant analyses conducted on the male and female speaker's /e/ productions. Grouping variables consisted of the contexts listed under "allophone groups" – each set of parentheses represents a group and the remainder of contexts another group.

For both the male and female speaker, relatively small values for Wilks's lambda and relatively high correct classification rates were obtained for the combination of a potential close-fronted allophone consisting of /^hese/, /^hexe/, and /^hpeta/, a potential open-retracted allophone consisting of /^hpera/ and /^hreta/, and a central allophone consisting of the remainder of contexts.

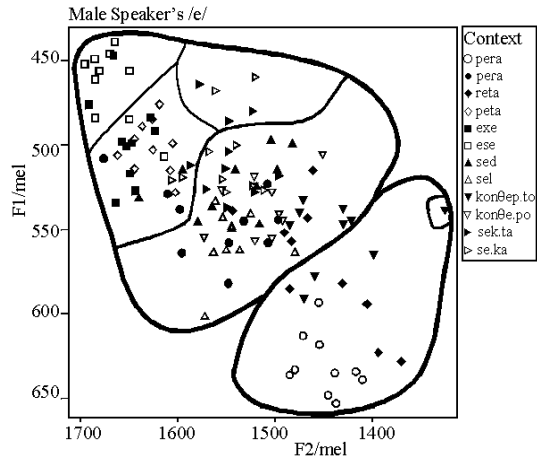


Figure 10. Largest six clusters resulting from a cluster analysis performed on male speaker's /e/ productions.

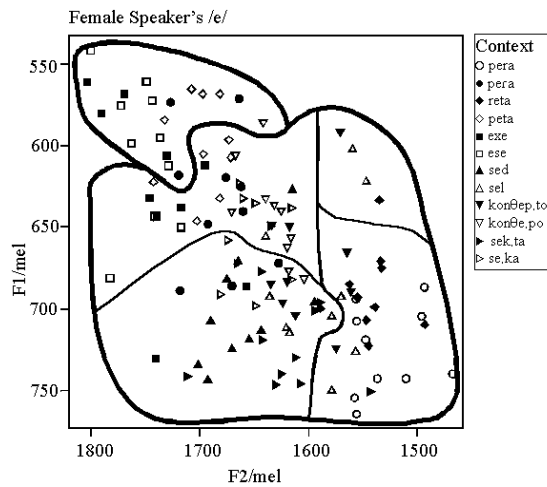


Figure 11. Largest five clusters resulting from a cluster analysis performed on female speaker's /e/ productions.

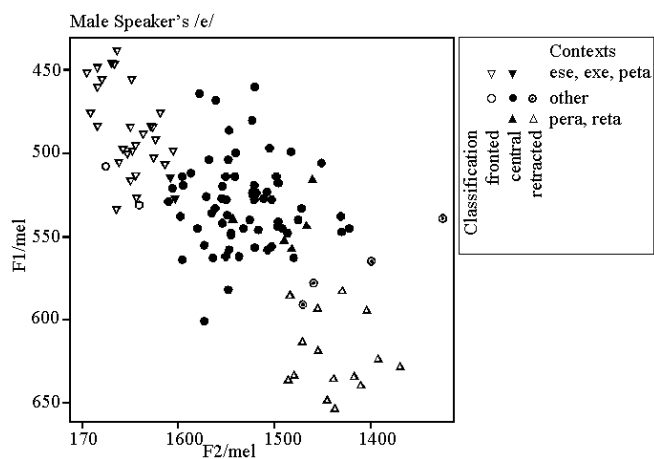


Figure 12. Classification into potential close-fronted, central, and open-retracted allophones from a discriminant analysis performed on the male speaker's /e/ productions.

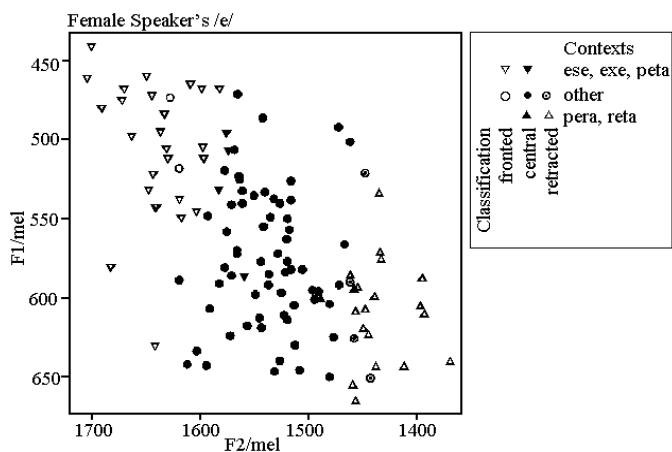


Figure 13. Classification into potential close-fronted, central, and open-retracted allophones from discriminant analysis performed on the female speaker's /e/ productions.

Classification results from this discriminant analysis are shown in Figures 12 and 13. The Wilks's lambda and correct-classification rates for this combination of allophones were very similar across speakers (see Table 5), indicating that the allophones were equally good matches for each speaker's productions. However, there were also indications of cross speaker differences: Including /kon^hθep.to/ in the male speaker's open-retracted allophone would have resulted in a lower Wilks's lambda and higher correct-classification rate for the male speaker (see Table 5); yet, this option was not even suggested by the cluster analysis on the female speakers' vowels where six of the ten vowels from this context fell well within the central cluster (see Figure 11).

The contexts for the open-retracted allophone, /^hpera/ and /^hreta/, differ from the remainder of contexts in that the vowels are adjacent to /r/. The allophone therefore appears to have an articulatory basis: the tip of the tongue is raised and the tongue dorsum lowered in order to articulate the apicoalveolar trill, and this tongue configuration affects the articulation of the vowel. Not all instances of /r/ were produced as trills however: For the /r/ in /^hreta/, the male speaker produced eight approximants and two trills, and the female speaker produced two approximants and eight trills (categorisation made both auditorily and by visual inspection of spectrograms). Every instance of /e/ following a trill had a lower F1 value than every instance of /e/ following an approximant, i.e. /e/ following [ɹ] was more open than /e/ following [r]. Again, an articulatory explanation is likely: greater tongue dorsum lowering would be expected for the approximant realisation than for the trill realisation. This finding goes against Navarro Tomás's (1960) suggestion that Cárdenas (1960) failed to find open allophones because /r/ may have been pronounced as an approximant rather than as a trill.

The contexts for the close-fronted allophone were /^hese/, /^hexe/, and /^hpeta/. The contexts /^hese/ and /^hexe/ differ from the remainder of the contexts in that the vowel is followed by a fricative (also preceded by a fricative since the preceding segment in the carrier sentence is /s/). The allophone may be due to articulatory constraints or aerodynamic effects associated with fricatives. The fact that /^hpeta/ was included in this allophone is problematic since there is no clear property of the /^hpeta/ context that would group it with the fricatives and contrast it with the remainder of the contexts.

4. GENERAL DISCUSSION AND CONCLUSIONS

The principal question to be answered in this study was whether the speakers produced open and close allophones of Spanish mid vowels in the contexts in which Navarro Tomás (1965) claimed such allophones exist. Statistical analyses of first and second formant values measured at the centre of Spanish mid vowels did not support the existence of these allophones. The results of the discriminant analysis carried out on the male speaker's putative /o/ allophones were clear: correct identification rates were just above 50% (50% would be obtained by chance) and Wilks's lambda was very close to 1 (indicating considerable overlap between putative allophones). The results for the female speaker's putative /o/ allophones and both speakers' putative /e/ allophones were less clear cut: it could be argued that correct identification rates in the 69–80% range and Wilks's lambdas in the .704–.797 range are in fact reasonably good indicators of the existence of the allophones. However, in all cases, it was possible to find alternative potential allophones resulting in much better statistical results: correct identification rates in the 84–99% range and Wilks's lambdas in the .319–.358 range⁸. This constitutes strong evidence that Spanish mid vowels should not be analysed into the open and close allophones claimed by Navarro Tomás (1965). If Spanish mid vowels are to be divided into allophones, the fronted versus retracted /o/ allophones and close-fronted versus central versus open-retracted /e/ allophones identified in the current study are better candidates. This classification is statistically justified and also has the advantage that the allophonic variation can generally be accounted for via articulatory constraints.

It would not be appropriate at this stage to give the allophones identified here the same status as was accorded to those identified by Navarro Tomás. The allophonic patterns found here may or may not be common among other Spanish speakers, and may or may not be peculiar to Spanish. Further research using a larger number of speakers and a larger number of phonetic contexts will be needed to determine

⁸ It should be noted that if one uses the results of a cluster analysis as grouping variables in a discriminant analysis on the same set of data, then results will almost always be better than if grouping variables not derived from that data set are used. However, this does not invalidate the findings here since: 1. The grouping variables were not based directly on cases identified by the cluster analysis, but on phonetic contexts which substantially coincided with the clusters. 2. The same grouping variables resulted in good scores for both participants, this constitutes a cross-validation (a test of the model built on one set of data against the an independent set of data) demonstrating that the results are not due to the vagaries of a single data set.

the extent to which the allophones identified in the present study can be generalised. Further research is also needed to determine whether the proposed articulatory bases for these allophones result in similar allophones in languages other than Spanish.

In conclusion, the results of a statistical analysis of formant values at the centre of Spanish mid vowels produced by two educated speakers from Madrid were not consistent with the existence of open and close allophones in the contexts claimed by Navarro Tomás (1965).

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