VOWEL VARIABILITY AND DISPERSION IN BRAZILIAN PORTUGUESE AND BRITISH ENGLISH: A CASE STUDY[1]

Adriana S. MARUSSO*

▪ ABSTRACT: This paper aims at studying the effect of vowel inventory size on acoustic vowel space in languages with different size inventories: Portuguese with seven oral vowels and English with eleven. Based on Dispersion Theory, this study analyzes acoustically vowel variability and dispersion in those two languages. Contrary to the theoretical predictions, in our data, the phonetic realization of English vowels is less precise and presents greater variability than those of the smaller system (Portuguese). As for vowel dispersion and acoustic space area, contrary to predictions, our Portuguese vowels are more dispersed, occupying more extreme positions in the vowel space, covering a greater acoustic area than those of English. Our results are aligned to other research that fails to find empirical proof for the predictions proposed by Dispersion Theory. We advance another interpretation for the facts. We hypothesize that the vowel systems of English and Portuguese are somehow unstable now; however, Dispersion Theory fails to capture such facts as it is based on categorical phonemes disregarding variable allophones. Probably, a theoretical approach that takes languages as dynamic and complex systems (ELLIS; LARSEN-FREEMAN, 2009) could offer stronger evidence to understand these facts. Such approach will be undertaken in the future.

▪ KEYWORDS: Vowel variability. Vowel dispersion. Acoustic analysis.

Introduction

The size of vowel inventories varies widely from language to language. However, cross-linguistic studies show that certain vowels and vowel inventory configurations are more frequent in natural languages. Maddieson (1984) analyzed 317 languages and observed that vowel inventories vary from languages having only 3 to others with 15 distinct vowel qualities. Two-thirds of the languages in this sample have between 5 and 7 vowel contrasts and the specific vowels most frequently preferred tend to be the same. The systems with five vowels generally have /i,e,a,o,u/, Spanish, for instance;

* UFOP - Universidade Federal de Ouro Preto. Instituto de Ciências Humanas e Sociais - Departamento de Letras. Mariana - MG - Brasil. 35420-000 – adrianamarusso@hotmail.com

[1] This paper presents some results from the research *"Vowel variability and dispersion in L1 and L2: a case study"*, developed during a Post-Doctorate course at POSLIN/UFMG.

those with seven have these five plus /ɛ,ɔ/, for example, Portuguese. In addition, the vowel inventories of most languages in the world include the vowels /i,a,u/. These three vowels define the extremes of the vowel space and are known as the *point vowels* or *corner vowels.* It is evident that vowel inventories are structured in a way that enhances contrast, by maximally dispersing vowels in the auditory-perceptual space. That is why /i,a,u/ are systematically present in natural languages; front vowels are generally unrounded while back vowels are rounded; and vowels tend to be spread along the periphery of the acoustic and perceptual space (BECKER-KRISTAL, 2010).

These tendencies observed in cross-linguistic studies raised the hypothesis that there are linguistic or physical (auditory and articulatory) constraints on possible speech sounds and their co-occurrence. That there are universal and/or language specific constraints that determine those most frequent patterns and that there is correlation between vowel inventory size and acoustic vowel space. Since Liljencrants; Lindblom (1972), Dispersion Theory has been used as the generic term for the theoretical approach that systematizes certain principles and makes explicit qualitative predictions in terms of how vowel systems are structured. The attempt to provide empirical evidence for those principles and predictions has rendered a number of studies. Some of them compare a large number of languages, e.g. Becker-Kristal (2010) and Livijn (2000), others contrast dialects, e.g., Recasens and Espinosa (2006, 2009), others contrast languages with small and large vowel inventories, e.g. Bradlow (1995) and Meunier, Espesser e Franck-Mestre (2006).

However, it has been difficult to understand the exact nature of these constraints and their interaction that produces the observed vowel inventories in natural languages. Thus, this study is interested in the effect of inventory size on the acoustic vowel spaces of languages with different inventory sizes: Portuguese with seven oral vowels and English with eleven. Taking the Dispersion Theory predictions, this paper aims to analyze vowel variability and dispersion in those two languages.

The article starts presenting the theoretical background that guided the analysis. Then, the methodology section describes the data, elicitation and recording; and acoustic measurement criteria. The results are presented separately for each language, first Portuguese, second English. In each case, individual results are analyzed first, and then they are compared to those of the group as a whole. After this analysis of the results for each language, the characteristics of vowel variability and dispersion of both systems is compared. Finally, our results are contrasted with the Dispersion Theory predictions.

Theoretical background

Previous studies regarding the structure of vowel systems have led to the development of several theoretical positions. Dispersion Theory claims that the vowels of a given language are arranged in the acoustic vowel space in such a manner that the potential for perceptual confusion between the distinct vowel categories is minimized. The theory is based on the following principles.

The first principle establishes that vowels should be maximally perceptually dispersed from one another (LILJENCRANTS; LINDBLOM, 1972). This means that extreme vowel qualities are preferred, because the more extreme the vowel is, the farther and more perceptually distinct it is from other vowels (BECKER-KRISTAL, 2010). Studies of the "Hyperspace Effect", such as Johnson, Flemming and Wright (1993) and Johnson (2000), provide some empirical support for this principle for speakers of English. In these studies, listeners judged as more prototypical exemplars of the point vowels /i,a,u/ those with extreme formant frequencies rather than stimuli with more natural formant ones. That is to say, when given the choice, listeners preferred a maximally dispersed version of the inventory.

The second principle states that the value of individual vowel qualities and their contribution to the inventories are relational. Thus, a vowel is good within an inventory if it is perceptually distant from other vowels in that inventory. The same vowel may be optimal for one inventory and unacceptable for another (BECKER-KRISTAL, 2010, p.12). Therefore, vowel qualities are adaptive. Minimal structural changes in the inventory may result in an arrangement of vowels in the inventory that is less dispersed, and so vowels shift and assume new positions to maximize dispersion (LILJENCRANTS; LINDBLOM, 1972). In their acoustic studies of the inventories of four Catalan dialects, Recasens e Espinosa (2006, 2009) present empirical evidence for the relational nature of inventories and the adaptive behavior of their vowels.

The third principle claims that maximization of dispersion is achieved by equidistant spacing between vowels (FERRARI-DISNER, 1984). This even spacing refers to a requirement that different pairs of adjacent vowels should maintain a certain minimal distance between them.

The cross-linguistic interpretation of the third principle makes three predictions (BECKER-KRISTAL, 2010). First, there should be an upper limit on the number of vowels in inventories; otherwise, the minimal distance cannot be maintained because the acoustic space is finite. This prediction is empirically supported by the typological finding that nine vowels tend to be the upper limit in inventories. Above that number, inventories become rare (CROTHERS, 1978; SCHWARTZ et al., 1997). Therefore, a system such as that of English, with eleven vowels, is atypical. Second, so as to keep minimal distance between vowels, the phonetic realization of them should be rather precise in larger inventories, while greater variability in phonetic realization is allowed in smaller inventories without violating the sufficient contrast criterion. Taking this prediction into account, it is expected to find greater variability in Portuguese vowels, as it is a less crowded inventory; and a more precise phonetic realization in English, with eleven vowels. However, there is no empirical evidence for the correlation between the number of vowels and phonetic precision (RECASENS; ESPINOSA, 2009). Third, inventories with a greater number of vowels should cover a larger acoustic space than those with fewer vowels. This prediction, at the same time, manifests the principle of vowel adaptive behavior in the case of point vowels /i,a,u/, which have to shift if the acoustic space size differs as a function of inventory complexity. Considering the fact that the languages here studied differ as to inventory size, the theory predicts that /i,a,u/ will occupy more peripheral positions in English than in Portuguese. On the other hand, it is expected that the English inventory, with eleven vowels, covers a greater area of the acoustic vowel space than Portuguese, with just seven vowels. This prediction has been addressed in several studies that compare acoustic data of vowel inventories differing in the number of their respective vowels. Some of these studies provide empirical support to the hypothesis that the acoustic space size differs as a function of inventory complexity, for instance, Ferrari-Disner (1983), Jongman, Fourakis and Sereno (1989), Guion (2003), Altamini and Ferragne (2005), Recasens and Espinosa (2006). Others; however, show null results, for example, Bradlow (1995), Meunier et al. (2003), Recasens and Espinosa (2009). This disparity shows that the theory demands improvement. Our work sets out to enrich the discussion arisen by the latter studies.

The chart below summarizes the principles of Dispersion Theory.

Chart 1 – Principles of Dispersion Theory

- Vowels should be maximally perceptually dispersed (LILJENCRANTS; LINDBLOM, 1972).
- More extreme qualities are preferred, as the more extreme the vowel is, the farther and more perceptually distinct it is from other vowels (BECKER, 2010).
- Maximization of dispersion results from equal spacing between vowels (FERRARI-DISNER, 1984). Therefore, different pairs of adjacent vowels should keep a certain minimal distance between them.
- The cross-linguistic interpretation of that last principle makes three predictions (BECKER, 2010): • An upper limit on the number of vowels in inventories is requested. Above that limit the minimal distance between vowels cannot be maintained because the acoustic space is finite. • So as to keep minimal distance between vowels, their phonetic realization should be more precise in larger inventories, whereas greater variability in phonetic realization is accepted in less crowded inventories without violating the sufficient contrast criterion. • Inventories with a greater number of vowels should cover a larger area in the acoustic space than those with fewer vowels.

Source: Our elaboration.

The principles of Dispersion Theory allow us to make certain predictions that lead to the following hypotheses regarding vowel variability and dispersion in English and Portuguese:

- H1: Greater variability is expected in Portuguese (with seven oral vowels) than in English (with eleven).

- H2: point vowels /i,a,u/ will occupy more peripheral positions in English, and English vowels will cover a larger area in the acoustic space than Portuguese vowels.

Methods

Taking into account the theoretical background presented in the previous section, this paper sets out to answer the following research questions:

Q1: What variability will be found in two vowel inventories of different size: Portuguese, with seven oral vowels, and English, with eleven?

Q2: What area will those vowels occupy In the acoustic vowel space?

The data

A specific experiment was developed to answer those two questions above. In order to turn the test material in both languages comparable, each oral vowel of Brazilian Portuguese (BP) was equated to the closest vowel in British English (RP) in acoustic, auditory and articulatory terms. Almost homophonous words were found in both languages so as to minimize coarticulatory effects. Examples of these words are exhibited in Chart 2 below.

Chart 2 – Examples of the data for each vowel

Brazilian Portuguese		***British English***	
Cida	[ˈsidə]	*cedar*	[ˈsiːdə]
sêca	[ˈsekə]	*sicker*	[ˈsɪkə]
peca	[ˈpɛkə]	*packer*	[ˈpækə]
paca	[ˈpakə]	*parker*	[ˈpɑːkə]
cola	[ˈkɔlə]	*collar*	[ˈkɒlə]
Lola	[ˈlolə]	*lawler*	[ˈlɔːlə]
luta	[ˈlutə]	*looter*	[ˈluːtə]

Source: Our elaboration.

Chart 2 above exemplifies the data with each vowel in stressed position, in both languages: the seven oral vowels in BP /i e ɛ a ɔ o u/ and the closest RP vowels /iː ɪ æ ɑː ɒ ɔː uː/. About ten different words for each stressed vowel were analyzed in each language (66 words in BP and 63 in RP). Each participant read each word once.

The total number of tokens analyzed in both languages was 516. The data consisted of words with penultimate stress, presented to the speaker in a printed frame question, *Did he say cedar? Ele diz Cida?* As the examples show, the data are accented and final in the utterance, keeping the same prosodic environment in both languages. The words have a CV.CV. syllable structure to minimize coarticulatory effects.

Elicitation and recording

Four native speakers of Brazilian Portuguese and four native speakers of British English served as volunteers in the experiment[2]. All of them were female; therefore, the data are comparable. None reported any hearing or speaking difficulties.

The Brazilian speakers were born in Belo Horizonte city, where they live. They are university students and they are between 20 and 26 years old. The British speakers were born and live in the southeast of England. Three of them are university students and one is a university professor, they are between 20 and 36 years old.

Six pages containing two columns of sentences or questions (including test material and fillers) were presented to the speakers in printed form. An extra introductory page was provided with instructions to read each sentence as naturally as possible, without pausing between words and to avoid reading the sentences as if they were just a list. The Brazilian speakers received the material in Portuguese and the British, in English.

The experimenter monitored each utterance for errors. If a mistake was detected, a repetition was requested immediately.

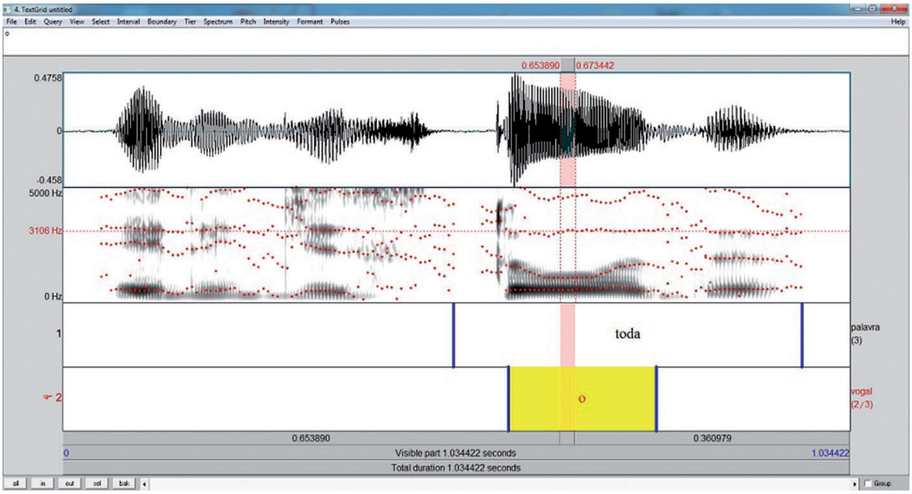
Recordings were made in the sound-attenuated recording studio at the Universidade Federal de Minas Gerais, Brazil. For the English data, recordings were made within a sound proof recording studio at the University of Edinburgh.

Acoustic measurements

The data were analyzed using PRAAT 5.3.23 © (BOERSMA; WEENINK) and were previously converted to a 10kHz sample rate which is more appropriate for vowel quality analysis in female speakers. Measurements were made using a temporal window which included the oscillogram, the spectrogram (wide band) and the formant tracts for the first five formants, as it is shown in the figure below.

[2] This work sets out to analyze new aspects of data recorded in previous stages of our research. These previous research projects had been submitted and approved by the Comitê de ÉticaemPesquisa/UFOP (CAAE-0003.0.238.000-08; CAAE-0054.0.238.000-9).

Figure 1 – Oscillogram and spectrogram of the question: *Ele diz toda?*



Source: Our elaboration.

To measure vowel quality, 20ms.of the central part of the vowel were selected and the program provided the mean for that portion in terms of the first three formants[3]. It is the highlighted portion of the vowel [o] in the example shown in Figure 1. When the vowel was too short, a single point at the center of the vowel was measured, avoiding the first and last 30ms., as those portions present greater coarticulatory effects.

Data normalization

So as to minimize physiological differences among speakers, data were normalized using the LOBANOV method. Such a procedure was necessary in order to make it possible to compare the results taking into account only linguistic information. LOBANOV uses a vowel-extrinsic formula[4]. According to Adank, Smits e Van Hout (2004), LOBANOV is one of the best methods for preserving sociolinguistic variation and effectively reduces anatomic/physiological variation in acoustic measurements. This method takes as input formant frequency values from different vowels produced by different speakers and generates output in normalized versions of those formant frequencies. Furthermore, LOBANOV makes easy-to-read plots of vowels that resemble F1/F2 formant plots. However, as the results are not in Hertz-like values,

---

3 All our analysis is based on the first two formants which are the most appropriate to describe vowel quality.

4 The formula is $F_{n[V]}^{N} = (F_{n[V]} - MEAN_n)/S_n$ where $F_{n[V]}^{N}$ is the normalized value for $F_{n[V]}$ (i.e., for formant *n* of vowel *V*). $MEAN_n$ is the mean value for formant *n* for the speaker in question and S_n is the standard deviation for the speaker's formant *n*.

scaling is necessary to convert the normalized values so that they look like those with their values in Hz. In this paper, all the graphs and tables present normalized formant values of F1 and F2[5]. Data normalization was done through the website[6] (THOMAS; KENDALL, 2007).

Results

The methods described above were crucial to obtain adequate and reliable results that would allow us to answer our research questions on vowel variability in languages with different inventory sizes (English: 11 vowels; Portuguese: 7 vowels) and on dispersion of those vowels in the acoustic space that is finite.

This section presents the results of the vowel quality analysis of the seven oral vowels in BP /i e ɛ a ɔ o u/ and the closest RP vowels /iː ɪ æ ɑː ɒ ɔː uː/. First, the results for each Brazilian participant are presented and interpreted. Then, the results from the four Brazilian speakers are compared so as to reach some understanding of how vowel variability and dispersion work in BP vowel system. Second, the same procedure is carried out with the results from the British participants. Finally, vowel variability and dispersion in both vowel systems are compared and analyzed according to the principles of Dispersion Theory.

Brazilian Portuguese results

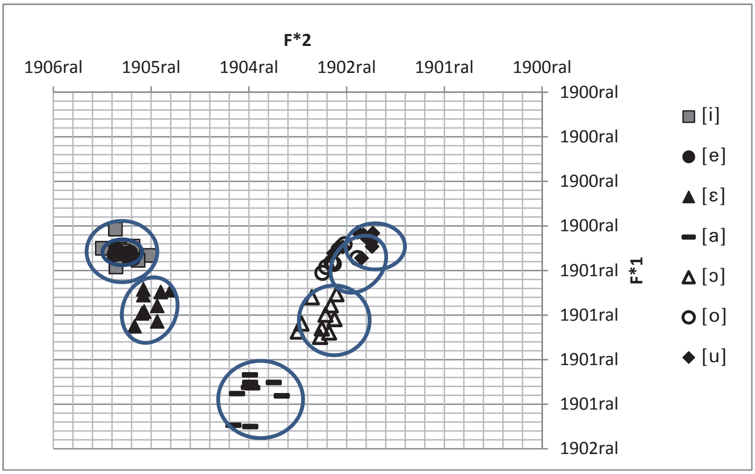
This section presents dispersion graphs showing the exact position of each token in the acoustic vowel space for each one of the four speakers. Then, a table shows the statistic description/analysis of the results in terms of mean value, median, standard deviation and maximum and minimum values. In each case, the graph provides information on vowel dispersion and the table on vowel variability.

5 F*1 and F*2 are used in order to show that the values are not in Hz.

6 Available in: <http://ncslaap.lib.ncsu.edu/tools/norm>. Access in: 17 mar. 2016.

Speaker 1 (BP)

Graph 1 – Vowel dispersion in BP (speaker1)



Source: Our elaboration.

The graph above shows:

- i/e merger: [i] occupies a larger area that includes [e]. Notice that [i] presents F1 near 400, which shows that it is being lowered;
- The merger does not result from greater variability;
- There are "contact points[7]" between e/ɛ and ɔ/o;
- Overlapping of some tokens of u/o;
- Symmetry of ɛ/ɔ, both between them and in relation to the other vowels;
- [a] occupies a larger area in the vowel space.

Table 1 – Descriptive statistics of speaker's 1 results (BP)

Spk. 1	[i] F*1	[i] F*2	[e] F*1	[e] F*2	[ɛ] F*1	[ɛ] F*2	[a] F*1	[a] F*2	[ɔ] F*1	[ɔ] F*2	[o] F*1	[o] F*2	[u] F*1	[u] F*2
Mean	355	2141	363	2144	477	2004	678	1480	507	1132	380	1057	339	940
Median	354	2158	362	2151.5	479	2036	662.5	1493.5	514	1117.5	382	1074	340	919
SD	**22.39**	**68.45**	**7.48**	**38.53**	**31.43**	**59.49**	**39.61**	**75.14**	**33.98**	**68.41**	**19.95**	**60.73**	**19.26**	**76.56**
Min.	307	2008	351	2090	442	1899	634	1332	453	1052	341	945	314	866
Max.	392	2250	374	2191	525	2085	750	1579	549	1250	405	1124	372	1067

Source: Our elaboration.

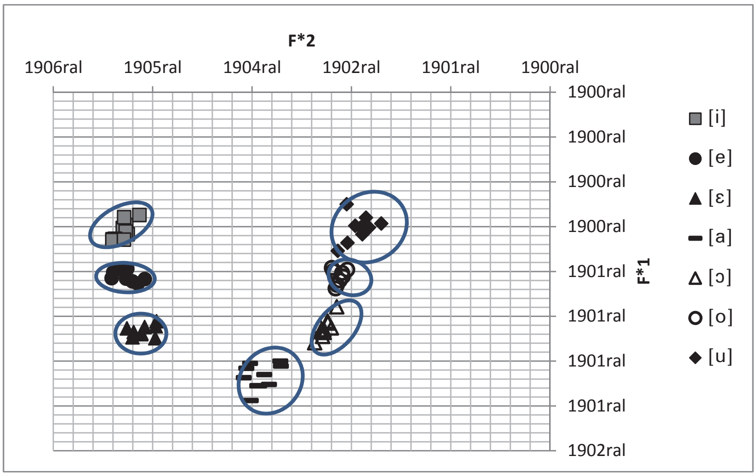
[7] We call "contact point" the contact between the ellipses of two or more vowels.

The table above shows mean, median, standard deviation, minimum and maximum values for F*1 e F*2 for each vowel produced by speaker 1. The standard deviation (in bold) provides information on the degree of variability. Those results show:

- All vowels vary more in terms of F2;
- The vowels [i a ɔ u] are those that vary the most in the horizontal dimension with standard deviation (SD) about 70;
- The vowel with the greatest variability is [a] and the one with the least variability is [e];
- The degree of variability of the other vowels is somehow uniform; however, back vowels [ɔ o u] vary more than their corresponding front ones [ɛ e i].

Speaker 2 (BP)

Graph 2 – Vowel dispersion in BP (speaker 2)



Source: Our elaboration.

The graph above shows:

- Vowels with well defined areas without any overlapping;
- The difference between i/eis mainly in terms of height of the tongue;
- The vowels are symmetric, equidistant and peripheral.

Table 2 – Descriptive statistics of speaker's 2 results (BP)

Spk. 2	[i] F*1	[i] F*2	[e] F*1	[e] F*2	[ɛ] F*1	[ɛ] F*2	[a] F*1	[a] F*2	[ɔ] F*1	[ɔ] F*2	[o] F*1	[o] F*2	[u] F*1	[u] F*2
Mean	310	2150	411	2134	533	2049	635	1459	526	1133	411	1064	303	963
Median	314	2144.5	415.5	2131	535	2057	633.5	1469	528	1138	407	1066	301.5	949.5
SD	**20.81**	**40.99**	**12.24**	**60.44**	**12.50**	**55.17**	**27.87**	**66.91**	**21.58**	**31.51**	**16.75**	**26.59**	**28.59**	**63.24**
Min.	274	2067	394	2040	511	1981	600	1355	479	1074	392	1021	250	850
Max.	330	2203	427	2207	549	2130	688	1542	559	1185	438	1099	354	1069

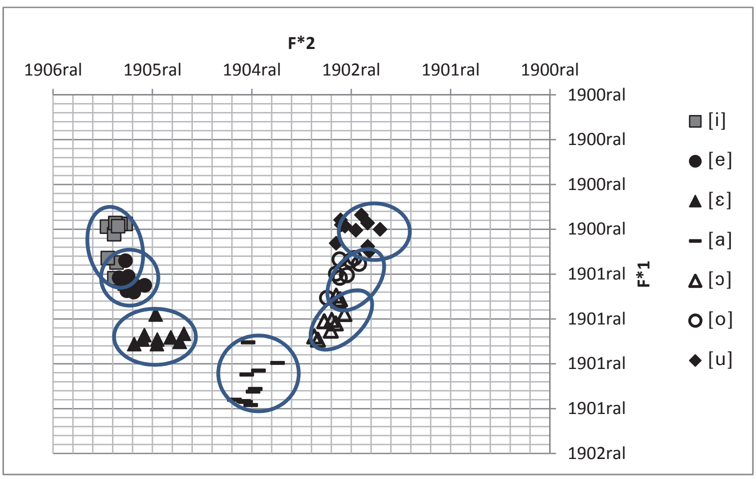
Source: Our elaboration.

Table 2 shows:

- All vowels vary more in terms of F2;
- The vowels that vary the most in the horizontal axis, in decreasing order, are [a u e] (SD between 60 and 67);
- There is little variability in F1 of [e ɛ o ɔ i];
- The two vowels that occupy a greater area in the acoustic vowel space are [a u]. Both vary the most in F1 and F2, as well;
- Front and back vowels are not distinguished by a different pattern of variability;
- This speaker's vowels present the least overall variability.

Speaker 3 (BP)

Graph 3 – Vowel dispersion in BP (speaker 3)



Source: Our elaboration.

The graph above shows:

- There is overlapping of i/e and, to a lesser degree, of u/o and o/ɔ;
- [i] presents some tokens with F1 above 400;
- There is some symmetry. Comparatively, front vowels are a bit more open than the corresponding back ones.

Table 3 – Descriptive statistics of speaker's 3 results (BP)

Spk. 3	[i] F*1	[i] F*2	[e] F*1	[e] F*2	[ɛ] F*1	[ɛ] F*2	[a] F*1	[a] F*2	[ɔ] F*1	[ɔ] F*2	[o] F*1	[o] F*2	[u] F*1	[u] F*2
Mean	333	2182	418	2114	539	1970	645	1503	498	1100	393	1036	304	974
Median	302.5	2184	425	2122	546	1978	659	1512.5	503.5	1088	388	1040	296.5	963
SD	**53.77**	**31.27**	**21.39**	**37.17**	**20.21**	**85.36**	**46.05**	**57.33**	**34.71**	**49.26**	**29.86**	**52.97**	**26.85**	**75.53**
Min.	286	2135	370	2039	490	1842	552	1371	448	1034	364	961	268	855
Max.	421	2229	440	2168	556	2092	692	1588	546	1186	453	1122	349	1076

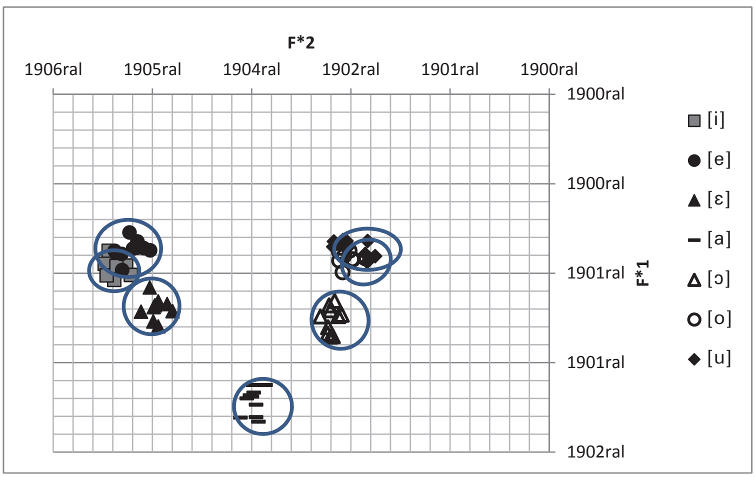
Source: Our elaboration.

Table 3 shows:

- All vowels, but [i], present greater variability in terms of F2;
- The most variable vowels, in decreasing order, are [ɛ a u].

Speaker 4 (BP)

Graph 4 – Vowel dispersion in BP (speaker 4)



Source: Our elaboration.

The graph above shows:

- There is great overlapping of i/eandu/o;
- [i] has F1 values above 400, some F1 values are above those of [e];
- There is symmetry between front and back vowels;
- All vowels cover approximately the same area in the vowel space, except [u e] that cover a slightly larger area;
- The overlapping of i/e and u/o results from a greater degree of opening of the high vowels i/u. The high vowels i/u have F1 values near 400.

Table 4 – Descriptive statistics of speaker's 4 results (BP)

Spk. 4	[i] F*1	[i] F*2	[e] F*1	[e] F*2	[ɛ] F*1	[ɛ] F*2	[a] F*1	[a] F*2	[ɔ] F*1	[ɔ] F*2	[o] F*1	[o] F*2	[u] F*1	[u] F*2
Mean	385	2192	347	2103	479	1980	687	1493	504	1099	367	1014	342	995
Median	382.5	2196	345	2098	476	1988	678	1491.5	496.5	1103.5	368	1020.5	338.5	1016
SD	**18.88**	**41.78**	**22.43**	**57.46**	**25.37**	**46.63**	**30.00**	**34.26**	**28.92**	**30.23**	**14.85**	**44.61**	**16.87**	**77.91**
Min.	350	2109	309	2012	432	1899	650	1430	462	1046	350	927	326	878
Max.	415	2241	393	2191	519	2058	732	1557	542	1154	398	1060	375	1089

Source: Our elaboration.

Table 4 shows:

- All vowels present greater variability in terms of F2. In decreasing order, [u e] are the most variable;
- The vowels [i o ɔ] are the least variable.

Summary of the results of variability in BP taking into account the four speakers together:

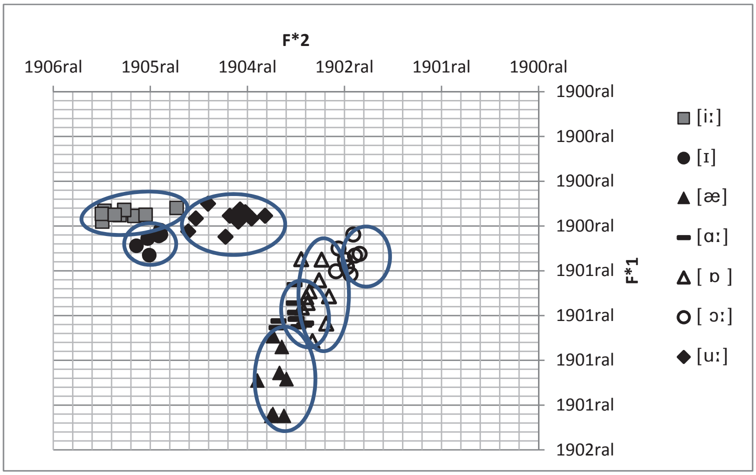
- Three speakers present merger or overlapping of high and higher-mid vowels;
- The cases of merger show high vowels with F1 values near 400, which indicates that high vowels are being lowered;
- The merger does not result from greater variability;
- Speaker 2 is the only one that has well defined areas for all vowels. Even if [i u] have F1 means above 300, there is no overlapping with the mid vowels because the latter also have higher F1 values ([e] 411 [ɛ] 533 [o] 411 [ɔ] 526);
- There is symmetry between front and back vowels;
- Speaker 3 presents the greatest overall variability (SD mean: 44.41), on the other hand, speaker 2, presents the least overall variability (SD mean: 34.66).

British English results

This section presents dispersion graphs showing the exact position of each token in the acoustic vowel space for each one of the four speakers. Then, a table shows the statistic description/analysis of the results in terms of mean value, median, standard deviation and maximum and minimum values. In each case, the graph provides information on vowel dispersion and the table on vowel variability.

Speaker 1 (RP)

Graph 5 – Vowel dispersion in RP (speaker 1)



Source: Our elaboration.

The graph above shows:

- There is overlapping of ɑː/ɒ;
- There are contact points of iː/ɪ, iː/uː, æ/ɑː, ɒ/ɔː;
- The vowels [iː uː æ ɒ] occupy a larger area in the vowel space. The high [iː uː] in terms of F2, and the low [æ ɒ] in terms of F1;
- There is no symmetry between front and back vowels.

Table 5 – Descriptive statistics of speaker's 1 results (RP)

Spk. 1	[iː] F*1	[iː] F*2	[ɪ] F*1	[ɪ] F*2	[æ] F*1	[æ] F*2	[ɑː] F*1	[ɑː] F*2	[ɒ] F*1	[ɒ] F*2	[ɔː] F*1	[ɔː] F*2	[uː] F*1	[uː] F*2
Mean	273	2143	331	1991	650	1354	501	1260	456	1160	372	982	283	1596
Median	274	2172	325	1981.5	643.5	1351.5	510	1253.5	458	1172.5	370.5	978	280	1569
SD	**8.41**	**123.88**	**20.21**	**49.52**	**69.32**	**47.94**	**29.66**	**49.41**	**57.35**	**51.23**	**29.21**	**41.95**	**21.93**	**127.36**
Min.	260	1865	309	1946	546	1299	431	1198	374	1080	319	922	250	1409
Max.	290	2250	365	2072	724	1449	527	1350	557	1223	408	1044	324	1805

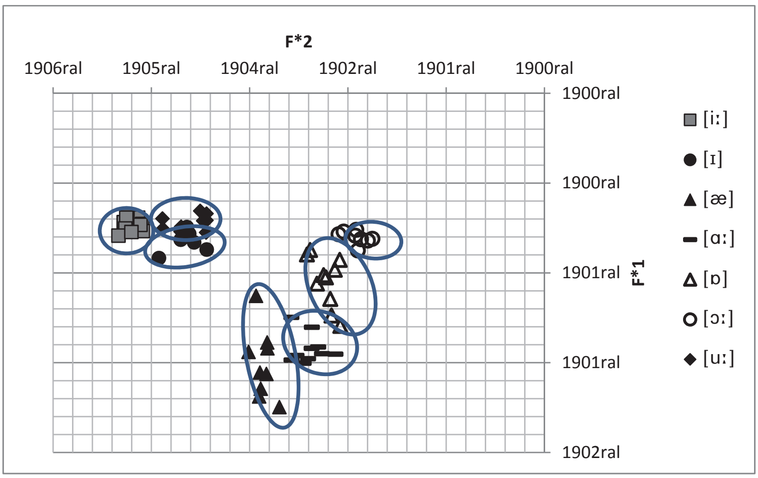
Source: Our elaboration.

Table 5 shows:

- The high vowels [iː uː] are the most variable in terms of F2 (SD >120);
- The low vowels [æ ɒ] are the most variable in terms of F1 (SD >57);
- The other vowels vary the least (SD < 40).

Speaker 2 (RP)

Graph 6 – Vowel dispersion in RP (speaker 2)



Source: Our elaboration.

The graph above shows:

- Little overlapping of ɪ/uː;
- Contact points of iː/ɪ, iː/uː, æ/ɑː, ɑː/ɒ, ɒ/ɔː;
- There is no symmetry between front and back vowels.

Table 6 – Descriptive statistics of speaker's 2 results (RP)

Spk. 2	[iː] F*1	[iː] F*2	[ɪ] F*1	[ɪ] F*2	[æ] F*1	[æ] F*2	[ɑː] F*1	[ɑː] F*2	[ɒ] F*1	[ɒ] F*2	[ɔː] F*1	[ɔː] F*2	[uː] F*1	[uː] F*2
Mean	293	2101	331	1824	603	1434	568	1198	418	1112	321	956	290	1809
Median	292	2112	329	1814	622	1444	580.5	1194	407.5	1101	320.5	954	290.5	1800.5
SD	**15.07**	**44.18**	**24.59**	**80.93**	**75.52**	**44.23**	**33.07**	**71.27**	**56.64**	**59.40**	**14.33**	**57.37**	**17.05**	**89.99**
Min.	273	2044	298	1719	451	1349	499	1064	349	1039	304	876	262	1720
Max.	317	2168	367	1962	699	1506	601	1288	518	1209	350	1048	310	1944

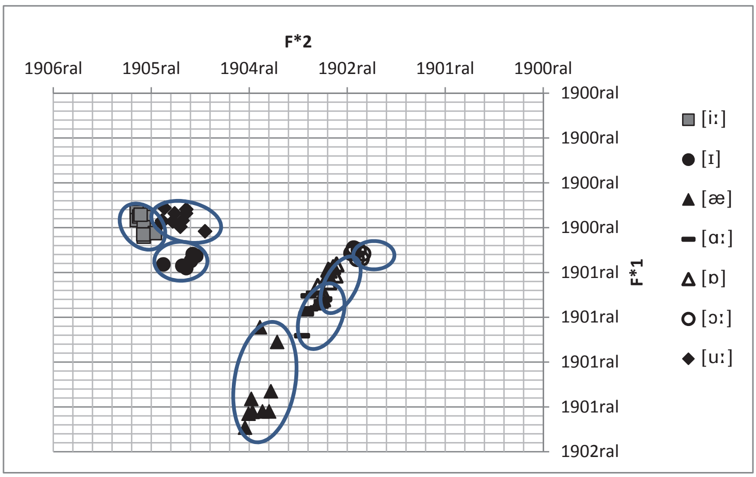
Source: Our elaboration.

Table 6 shows:

- All vowels, but [æ], vary more in F2. In decreasing order, the most variable in F2 are [uː ɪ ɑː];
- The vowels [æ ɒ uː ɪ ɑː] are the most variable (SD between 50 and 60).

Speaker 3 (RP)

Graph 7 – Vowel dispersion in RP (speaker 3)



Source: Our elaboration.

The graph above shows:

- Little overlapping of iː/uː,ɑː/ɒ;
- Contact points of iː/ɪ, ɪ/uː; ɒ/ɔː;
- [æ] occupies the greatest area in the vowel space and [ɔː] the smallest one.

Table 7 – Descriptive statistics of speaker's 3 results(RP)

Spk. 3	[iː] F*1	[iː] F*2	[ɪ] F*1	[ɪ] F*2	[æ] F*1	[æ] F*2	[ɑː] F*1	[ɑː] F*2	[ɒ] F*1	[ɒ] F*2	[ɔː] F*1	[ɔː] F*2	[uː] F*1	[uː] F*2
Mean	293	2044	376	1827	668	1447	477	1170	413	1096	357	953	280	1866
Median	291	2040	378	1810	710	1446	475	1171	406.5	1094.5	354.5	959	284	1866.5
SD	**21.06**	**26.58**	**12.44**	**60.36**	**77.43**	**56.75**	**28.28**	**39.22**	**26.23**	**29.70**	**8.91**	**22.62**	**16.87**	**68.99**
Min.	265	1982	359	1771	522	1358	446	1117	382	1055	346	918	256	1726
Max.	320	2075	390	1939	746	1522	541	1231	460	1151	370	980	308	1949

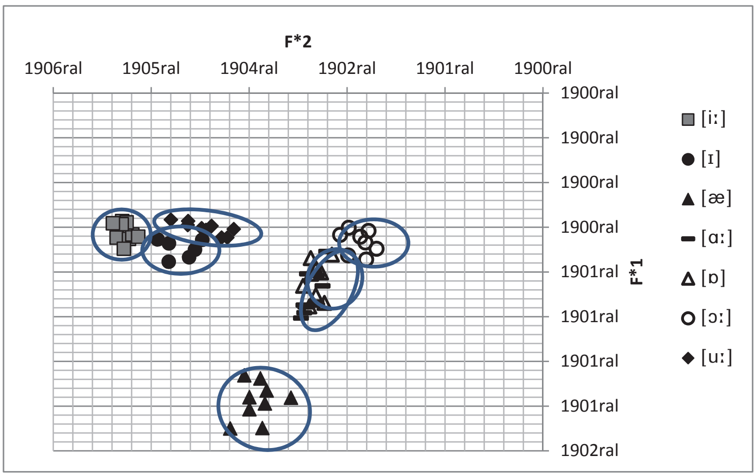
Source: Our elaboration.

Table 7 shows:

- All vowels, but [æ], vary the most in F2. In decreasing order, the most variable in F2 are [uː ɪ];
- [æ] presents the greatest general variability (SD mean: 67.09).

Speaker 4 (RP)

Graph 8 – Vowel dispersion in RP (speaker 4)



Source: Our elaboration.

The graph above shows:

- Great overlapping of ɑː/ɒ;
- Little overlapping of ɪ/uː;
- Contact points of iː/ɪ, ɑː/ɒ/ɔː;
- [æ] occupies the greatest area in the vowel space;
- There is symmetry only between iː/ɔː.

Table 8 – Descriptive statistics of speaker's 4 results(RP)

Spk. 4	[iː] F*1	[iː] F*2	[ɪ] F*1	[ɪ] F*2	[æ] F*1	[æ] F*2	[ɑː] F*1	[ɑː] F*2	[ɒ] F*1	[ɒ] F*2	[ɔː] F*1	[ɔː] F*2	[uː] F*1	[uː] F*2
Mean	309	2135	348	1852	688	1457	448	1179	414	1160	333	938	302	1721
Median	304.5	2136.5	343	1858.5	681	1443	470.5	1181	402.5	1163.5	327.5	920	301	1710
SD	**20.98**	**37.35**	**20.93**	**89.99**	**42.36**	**87.26**	**47.31**	**45.15**	**40.98**	**42.17**	**25.90**	**63.17**	**13.32**	**99.57**
Min.	286	2067	327	1740	631	1287	354	1107	361	1078	301	850	283	1579
Max.	348	2196	377	1968	750	1597	503	1236	477	1225	372	1036	323	1900

Source: Our elaboration.

Table 8 shows:

- Great variability of [uː ɪ æ] in F2 (SD > 80);
- Great variability of [ɑː æ ɒ] in F1(SD >40);
- The least variable vowel is [iː].

Summary of the results of variability in RP taking into account the four speakers together:

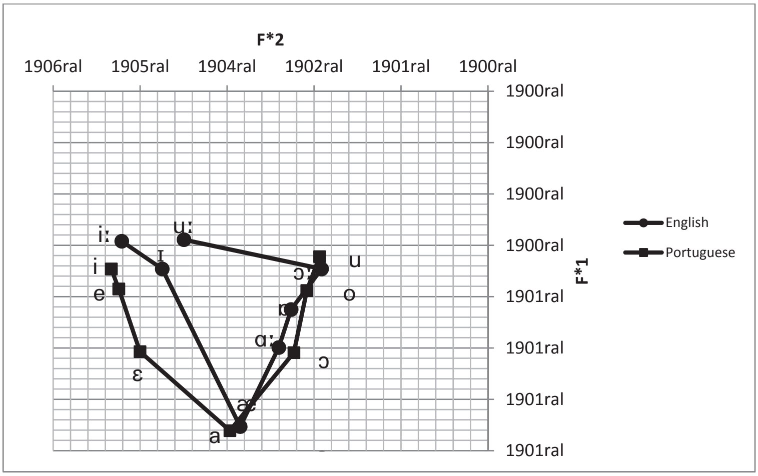
- There is some overlapping of [ɪ uː] and [ɑː ɒ];
- [uː] is very fronted;
- [æ] presents the greatest variability;
- There is no symmetry between front and back vowels;
- Hypothesis of chain shift: [uː] is fronted, therefore, it leaves empty the space in the high back region. At the same time, the back vowels [ɑː ɒ ɔː] become higher and [æ] becomes lower and less fronted[8].

Comparison of vowel dispersion and variability in English and Portuguese

This section compares vowel dispersion and variability in the two languages. In order to do so, the results of the four speakers together of each language will be used. A dispersion graph was drawn using the mean for each vowel in each language to show the vowel system configuration.Then, a table with the means and SD for each vowel makes it possible to compare variability in both languages.

[8] Our results for [uːæ] in RP have been corroborated by Paul Boersma (2012). (personal communication): "I just looked into the 2000 version of Gimson's book, edited by Alan Cruttenden. He explicitly states that /u/ has been fronted and /æ/ has fallen during the last 30 years (pages 83, 99). The formants that he shows are quite close to the ones that you found."

Graph 9 –Vowel dispersion in English and Portuguese



Source: Our elaboration.

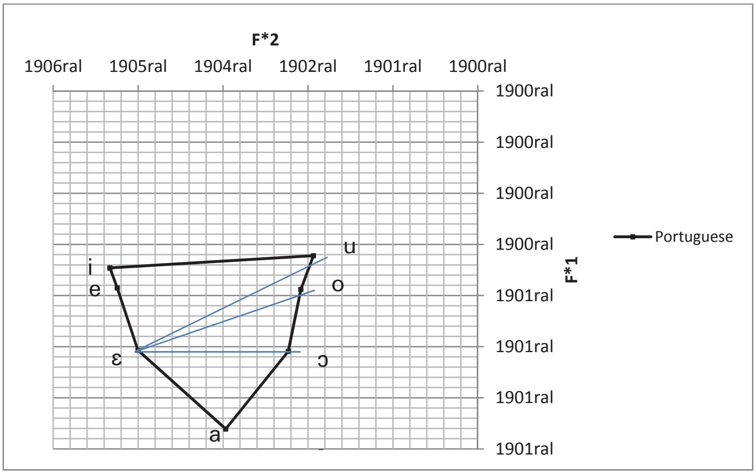
The graph above was made using the means of all data for each vowel as produced by the four speakers of each language together. The graph shows:

- Portuguese vowels are more dispersed and occupy more peripheral areas of the vowel space;
- English high vowels are higher than those in Portuguese;
- In Portuguese, there is great symmetry between front and back vowels.

In order to test whether this visual impression corresponded to reality, the vowel space area for each language was calculated using Heron's method[9] (JACEWICZ; FOX; SALMONS, 2007). To do so, the total vowel space was divided into triangles. The graphs 10 and 11 below show this procedure.

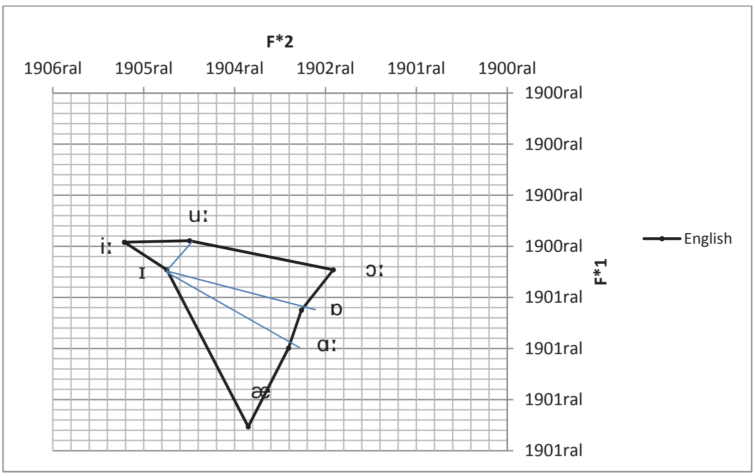
[9] This method is used for calculating the area of a triangle when you know the length of all three sides. Let *a,b,c* be the lengths of the sides of a triangle. The area is given by: $A = \sqrt{p(p-a)(p-b)(p-c)}$ where p is half the perimeter, or $\frac{a+b+c}{2}$.

Graph 10 – Vowel space area in Portuguese



Source: Our elaboration.

Graph 11 – Vowel space area in English



Source: Our elaboration.

The total sum of the triangles' area of the vowel space was 12.20 in Portuguese and 8.65 in English. Therefore, Portuguese vowels occupy an area about 30% larger than that of English vowels.

Table 9 – Means and SD of English and Portuguese vowels

English	[iː] F*1	[iː] F*2	[ɪ] F*1	[ɪ] F*2	[æ] F*1	[æ] F*2	[ɑː] F*1	[ɑː] F*2	[ɒ] F*1	[ɒ] F*2	[ɔː] F*1	[ɔː] F*2	[uː] F*1	[uː] F*2	SD Mean
mean	292	2106	346	1873	653	1425	499	1203	425	1132	346	957	289	1748	
SD	20.93	77.72	26.37	97.06	72.22	71.37	56.80	62.11	48.68	53.63	28.42	49.05	18.92	140.11	**58.81**
Portuguese	**[i] F*1**	**[i] F*2**	**[e] F*1**	**[e] F*2**	**[ɛ] F*1**	**[ɛ] F*2**	**[a] F*1**	**[a] F*2**	**[ɔ] F*1**	**[ɔ] F*2**	**[o] F*1**	**[o] F*2**	**[u] F*1**	**[u] F*2**	
mean	346	2166	385	2123	507	2001	661	1484	509	1116	388	1042	322	968	
SD	42.04	50.57	35.46	49.98	37.04	67.88	41.49	60.29	30.86	48.61	26.13	49.24	29.35	73.40	**45.88**

Source: Our elaboration.

Table 9 shows the mean values for each vowel of all data for the four speakers of each language. There are some similarities and some differences.

- Similarities:

- All vowels (except [æ]) present greater variability in terms of F2;
- The degree of variability of front and back vowels presents no symmetry nor any differentiating pattern;
- The greatest variability in F2 is in [u] in Portuguese and in the corresponding nearest vowel in English [uː];
- Portuguese [a] and the corresponding nearest vowel in English [ɑː] have the second higher SD in F1;
- The vowels that vary the least are [o]in Portuguese and in the corresponding nearest vowel in English [ɔː].

- Differences between the systems:

- English presents greater general variability than Portuguese. The SD mean for all vowels is 58.81 for English and 45.88 for Portuguese;
- The progression of variability is also different in both languages. In decreasing order of variability, English has: uː>æ>ɪ>ɑː>ɒ>iː>ɔː; while Portuguese has: ɛ>u>a>i>e>ɔ>o.

After presenting our results, we resume our research questions:

Q1: What variability will be found in two vowel inventories of different size: Portuguese, with seven oral vowels, and English, with eleven?

In our data, English presented greater general variability than Portuguese. In both languages, vowels tend to vary more in terms of tongue projection or retraction than in terms of height of the tongue. Maybe this is so because both languages make more distinctions in the vertical than in the horizontal axis. For instance, in English, there is contrast between iː/ɪ, but there is no opposition between iː/ɨ. That is to say, in both languages there are front and back vowels that are distinguished mainly by tongue height. On the other hand, there is no symmetry in the degree of variability between front and back vowels, nor any distinguishing pattern. In each language, variability affects each vowel differently.

Q2: What area will those vowels occupy in the acoustic vowel space?

Portuguese vowels are more dispersed and occupy more peripheral areas in the acoustic space. There is great symmetry in the spatial distribution of front and back vowels. Spacing between higher-mid and lower-mid vowels tends to be equidistant with that between lower-mid and low vowels. Such even spacing is not present between high and higher-mid vowels due to the lowering of the former.

Portuguese vowels draw a *v* shape in the acoustic space, with front and back vowels clearly distinct. English vowels draw a triangle due to the fronting of [uː]. In English, the highest back vowel is [ɔː]. Vowels are not evenly spaced, for example, in terms of F1, the distance between [ɪ æ] or between [æ ɑː] is greater than that between other vowels.

Final remarks

We summarize here those predictions of Dispersion Theory that gave rise to our hypotheses:

- So as to keep minimal distance between vowels, their phonetic realization should be more precise in larger inventories, whereas greater variability in phonetic realization is accepted in less crowded inventories without violating the sufficient contrast criterion;
    - H1: Greater variability is expected in Portuguese (with seven oral vowels) than in English (with eleven).
- Inventories with a greater number of vowels should cover a larger area in the acoustic space than those with fewer vowels. This prediction also manifests the principle of vowel adaptiveness in the case of point vowels /i,a,u/, which have to shift if the acoustic space size differs as a function of inventory complexity.
    - H2: point vowels /i,a,u/ will occupy more peripheral positions in English, and English vowels will cover a larger area in the acoustic space than Portuguese vowels.

Our results seem to contradict those predictions of Dispersion Theory. As to vowel variability (cf. H1 above), in our data, the phonetic realization of the vowels in the larger inventory, i.e., in English, is less precise and presents greater variability, both in terms of F1 and F2, than those of the Portuguese system, therefore, H1 is refuted.

As to vowel dispersion and area in the acoustic space, again contrary to expectations, our results refute H2 above, because Portuguese vowels are more dispersed and peripheral occupying a larger acoustic area than those of English. However, it is crucial to highlight that the fronting of [uː] in English might have broken the system stability. That is why we raise the hypothesis of a vowel chain shift that also affects the back vowels [ɑː ɒ ɔː], which are being raised and drags [æ] to a lower and less fronted position.

On the other hand, Portuguese system tends to respect the premise that vowels should be evenly spaced (FERRARI-DISNER, 1984). However, the lowering of the high vowels [i u] makes them closer to the higher-mid [e o]. This lowering of the high vowels in Portuguese demands further research.

As previously pointed out in the Theoretical Background session and corroborated by our results, the predictions of Dispersion Theory are controversial. We have already seen that some works support the theory while some empirical studies contest it. Our results allow us to raise the hypothesis that the systems of English and Portuguese are somehow unstable at present. In English, the fronting of [uː] breaks the expected balance of point vowels /i,a,u/, vowel [ɔː] occupies the space left empty by [uː] and ends up dragging a chain shift that affects not only the back vowels but also vowel [æ]. That is to say, there is ongoing reorganization of vowel space in English.

In Portuguese, there is great overlapping of high and higher-mid vowels in stressed position. That is not the consequence of greater variability, but of the lowering of high vowels [i u]. As in English, there is ongoing reorganization of vowel space in Portuguese.

It seems necessary to investigate such reorganization of vowel space in both languages taking into account that vowel systems are both changing and stable at the same time. As shown in this paper, Dispersion Theory fails to capture such facts as it is based on categorical phonemes and deterministic predictions. Probably, a theoretical approach that takes languages as complex dynamic systems (ELLIS; LARSEN-FREEMAN, 2009) might offer more grounded elements that would shed light on the facts here presented. Such proposal will be undertaken in future studies.

MARUSSO, A. Variabilidade e dispersão vocálica em Português Brasileiro e Inglês Britânico: um estudo de caso. **Alfa**, São Paulo, v.60, n.1, p.179-204, 2016.

- *RESUMO: Este artigo objetiva discutir o efeito do tamanho do inventário no espaço acústico de línguas com inventários vocálicos de tamanhos diferentes: português com sete e inglês com onze vogais. Partindo das predições da Teoria de Dispersão Vocálica, este estudo analisa acusticamente a variabilidade e dispersão vocálica nessas duas línguas.*

Contrariamente ao previsto pela teoria sobre a variabilidade vocálica, em nossos dados, a realização fonética das vogais do sistema vocálico maior (inglês) é menos precisa e apresenta maior variabilidade que as do português. Quanto à dispersão vocálica, também contrariando o previsto, as vogais do português estão mais dispersas e periféricas cobrindo uma área acústica maior que as do inglês. Nossos resultados estão em consonância com trabalhos que questionam a comprovação empírica das predições da Teoria de Dispersão. Nosso avanço é quanto à interpretação dos fatos. Levanta-se a hipótese que os sistemas vocálicos do inglês e português estejam parcialmente instáveis atualmente, entretanto, a Teoria de Dispersão não captura esses fatos por estar mais pautada em fonemas estanques que em alofones variáveis. Possivelmente, uma abordagem teórica que entenda as línguas como sistemas dinâmicos e complexos (ELLIS; LARSEN-FREEMAN, 2009) ofereça elementos mais sólidos para a compreensão dos fatos apresentados. Tal proposta será fomentada futuramente.

- *PALAVRAS-CHAVE: Variabilidade vocálica. Dispersão vocálica. Análise acústica.*

REFERENCES

ADANK, P.; SMITS, R.; VAN HOUT, R. A comparison of vowel normalization procedures for language variation research. **Journal of the Acoustical Society of America**, New York, v.116, n.5, p.3099-3107, 2004.

ALTAMINI, J. E.; FERRAGNE, E. Does vowel system size depend on language vowel inventories? evidence from two Arabic dialects and French. In: EUROPEAN CONFERENCE ON SPEECH COMMUNICATION AND TECHNOLOGY, 9., 2005, Lisboa. **Proceedings**… Lisboa: Interspeech-Eurospeech, 2005. p. 2465-2468.

BECKER-KRISTAL, R. **Acoustic typology of vowel inventories and dispersion theory**: **Insights from a large cross-linguistic corpus**. 2010. 235f. Dissertation (Doctor of Philosophy in Linguistics) - University of California, Los Angeles, 2010.

BOERSMA, P.; WEENINK, D. **PRAAT**: doing phonetics by computer 5.3.23©. Disponível em: <http://www.fon.hum.uva.nl/praat/> Acesso em: 21 ago. 2012.

BRADLOW, A. R. A comparative acoustic study of English and Spanish vowels. **Journal of the Acoustical Society of America**, New York, v.97, n.3, p.1916-1924, 1995.

CROTHERS, J. Typology and universals of vowel systems. In: GREENBERG, J. H.; FERGUSON, C. A.; MORAVCSIK, E. A. (Ed.). **Universals of human language**. Stanford: Stanford University Press, 1978. p. 93-152. (Phonology ; v. 2).

ELLIS, N.; LARSEN-FREEMAN, D. Language is a complex adaptive system: position paper. **Language Learning Research Club**, Michigan, v.59, sup. 1, p.1-26, dec. 2009.

FERRARI-DISNER, S. Insights on vowel spacing. In: MADDIESON, I. **Patterns of sounds**. Cambridge: Cambridge University Press, 1984. p.136-155.

______. **Vowel quality**: the relation between universal and language-specific factors. 1983. 171f. Dissertation (Doctor of Philosophy in Linguistics) - University of California, Los Angeles, 1983.

GUION, S. The vowel systems of Quichua-Spanish bilinguals. **Phonetica**, Basel, v.60, p.98-128, 2003.

JACEWICZ, E.; FOX, R. A.; SALMONS, J. Vowel space areas across dialects and gender. In: INTERNATIONAL CONGRESS OF PHONETIC SCIENCES, 16., Saarbrücken. **Proceedings**… Saarbrücken: [s.n.], 2007. p.1465-1468.

JOHNSON, K. Adaptive dispersion in vowel perception. **Phonetica**, Basel, 57, p.181-188, 2000.

JOHNSON, K.; FLEMMING, E.; WRIGHT, R. The hyperspace effect: phonetic targets are hyperarticulated. **Language**, Baltimore, v.69, p.505-528, 1993.

JONGMAN, A.; FOURAKIS, M.; SERENO, J. The acoustic vowel space of modern Greek and German. **Language and Speech**, Middlesex, v. 32, p.321-348, 1989.

LILJENCRANTS, J.; LINDBLOM, B. Numerical simulation of vowel quality systems: the role of perceptual contrast. **Language**, Baltimore, v. 48, p. 839-862f, 1972.

LIVIJN, P. Acoustic distribution of vowels in differently sized inventories: hot spots or adaptive dispersion? **PERILUS**, Stockholm, v.23, p. 93-96, 2000.

MADDIESON, I. **Patterns of sounds**. Cambridge: Cambridge University Press, 1984.

MEUNIER, C.; ESPESSER, R.; FRENCK-MESTRE, C. Phonetic variability as a static/dynamic process in speech communication: a cross linguistic study. **Laboratory Phonology (LabPhon)**, Paris, v.10, p.129-130, 2006.

MEUNIER, C. et al. Production and perception of vowels: does the density of the system play a role? In: INTERNATIONAL CONGRESS OF PHONETIC SCIENCES, 15., 2003, Barcelone. **Proceedings**… Barcelona: Université Autonome de Barcelone, 2003. p.723-726.

RECASENS, D.; ESPINOSA, A. Dispersion and variability in Catalan five and six peripheral vowel systems. **Speech Communication**, Amsterdam, v.51, p. 240-258, 2009.

______. Dispersion and variability in Catalan vowels. **Speech Communication**, Amsterdam, v.48, p. 645-666, 2006.

SCHWARTZ, J. L. et al. Major trends in vowel system inventories. **Journal of Phonetics**, London, v.25, p. 233-253, 1997.

THOMAS, E. R.; KENDALL, T. **NORM**: the vowel normalization and plotting suite. 2007-2015. Disponível em: <http://lingtools.uoregon.edu/norm/norm1.php>. Acesso em: 17 mar. 2016.

Received in July 2014

Approved in October 2014