A Contrastive Analysis of Schwa in English and Portuguese

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1. Introduction

The nature of representations is an important topic in the current phonological literature. Results indicate that languages use important and detailed phonetic information to categorize its sounds (Pierrehumbert, 1999). Furthermore, when the relationship between perception and production is addressed the notion of a single underlying representation is deeply questioned. This paper intends to be a contribution to this current debate by analyzing the phonetic and phonological properties of schwa in Portuguese and English. The varieties to be analyzed are: Minas Gerais Brazilian Portuguese (BP) and Southeastern British English (RP). The main question to be addressed is whether or not the schwa has similar properties when related to a set of vowels, as in English, and when it relates to a single vowel, as in Portuguese. Similar properties to be investigated are the quality of schwa depending on the nature of adjacent vowels and also the durational patterns of schwa in both languages. We first present a quick review of the literature in order to set the relevant theoretical background. Then, we indicate the major objectives of the paper and we describe the methods used in the experiment. Finally, we discuss the results indicating the major conclusions to be drawn from the research presented in this paper.

2. Background

Variability in the articulatory and acoustic realization of segments has been studied from different approaches. In terms of articulatory constraints on variability, there are essentially two descriptions of the differences between vowels with respect to the amount of contextual variation. One of these is the *target undershoot* approach and the other one is the gestural approach to coarticulation. The former approach suggests that the degree of coarticulation depends on the distance between, and the time available to reach segmental targets (Stevens & House, 1963; Lindblom, 1963). The second approach understands coarticulation as regulated by the degree of articulatory compatibility between segments (Recasens, 1986, 1991; Browman & Goldstein, 1992).

Different authors have studied the variability of the neutral vowel in English, namely the schwa. Recasens (1991) claims that schwas are the vowels with the highest degree of variability. The author attributes this to "the inherently low requirements on the tongue configuration during the production of this vowel" (p.187). Keating (1988:30) suggests that featural "underspecification may persist into phonetic representation" (p.30). If a segment is phonetically unspecified for a certain feature, instead of assimilating the feature values of neighboring sounds, it is simply interpolated through. In the same line, Bates (1995) shows that medial schwa is interpolated in RP English. However, Bates shows that a final schwa in BE does not suffer interpolation. This indicates the different behavior of a schwa in medial position and in final position. Browman & Goldstein (1992) also investigated English schwa and proposed that schwa has a target, but "its target is the mean of all the vowels, and is completely overlapped by the following vowel" (p.54). This paper investigates this claim with regards to final utterance schwas.

Taking into account that in English basically any full vowel may reduce to schwa, it is possible to think that this phonological fact is phonetically realized by a neutral vowel that has a target which is the mean of all full vowels. This is thus the main claim of Browman and Goldstein (1992). If their proposal is correct then, a different phonetic behavior from the schwa in English could be expected for the Brazilian Portuguese schwa, which is exclusively the unstressed variant of /a/. This paper intends to contribute to a better understanding of these facts. That is, whether or not a schwa has similar properties when related to a set of vowels, as in English, and when it relates to a single vowel, as in Portuguese.

On the other hand, vowel quantity or duration is another relevant aspect of vowel reduction. In Portuguese, Cagliari & Abaurre (1986) state that the final syllable in an utterance is always the longest one, no matter whether it is stressed or not, presenting thus a reduced vowel with significant duration. Massini-Cagliari (1992) shows that accented words are the most prominent in an utterance at all levels: pitch, duration, vowel quality, etc. and the least vulnerable to compression. At word level, the stressed syllable is the most prominent and the one that does not suffer vowel compression in contrast to unstressed vowels. However, it would be interesting to investigate whether such a strong vowel, as it is the case of a stressed one, may interfere on the production of other adjacent vowels.

This is somewhat what Turk & Sawusch (1997) carried out for English. They showed that accentual lengthening goes beyond the stressed syllable. In fact, in two-syllable words with the stress pattern stressed-unstressed, that is (s w), not only the primarily stressed syllable but also the post-tonic one is lengthened. This paper intends to investigate Turk & Sawusch (1997) with regards to Brazilian Portuguese and verify this claim for Southeastern English.

Crosswhite (1999) proposes a phonological analysis for vowel reduction in several languages and states that a schwa is non-moraic and therefore it is never longer than 40ms. We will also consider in this paper Crosswhite's claim with regards to BP and BE.

Considering the facts exposed above this paper investigates mainly the following issues: a) the quality and quantity of a final schwa in BE and BP, b) whether an adjacent vowel affects a schwa and c) Crosswhite's (1999) claim that a schwa is never longer than 40ms. The following section describes the major characteristics of the experiment.

3. Method

3.1 The data

A specific experiment was designed to answer the three questions posed above. In order to obtain comparable testing material in both languages, each oral vowel of BP was equated to a vowel in BE and almost homophonous words were found in both languages. Examples of these words are listed in Table 1.

Table 1. Sample words investigated in the experiment

Brazilian Portuguese		***Bristish 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]

Table 1 lists sample words with each stressed vowel in both languages. There were about ten different words for each stressed vowel in each language. Each word presented two syllables with penultimate stress, namely a (s w) pattern. Table 1 shows that seven primarily stressed oral vowels in BP /i e ɛ a ɔ o u/ and seven primarily stressed oral vowels in BE /iː ɪ æ ɑː ɒ ɔː uː/ were considered.

Participants were presented with a printed frame which showed a question to be read: *Did he say* *cedar?* for BE and *Ele diz* *Cida?* for BP. Notice in the examples that the tested words were accented and appeared in the final position in the utterance. Words also had a CV.CV syllable pattern in order to minimize coarticulation. Nasal consonants were avoided due to potential nasalization in Brazilian Portuguese. Thus, all data presented only oral vowels in both languages.

Brazilian Portuguese participants were presented with a printed frame containing Brazilian Portuguese sentences. English participants were presented with a printed frame containing English sentences. Further information as to how the experiment was carried out is provided in the following sections.

3.2 Elicitation and recording

Four native speakers of Brazilian Portuguese and four native speakers of British English participated as volunteers in the experiment. All participants were female making thus data comparable for acoustic measurements. None of the participants reported any hearing or speaking difficulties.

Participants were presented with a six pages printed frame which contained instructions and the list of sentences to be read. The introductory page provided a set of instructions indicating to participants how they should carry out the reading. Instructions requested them to read each sentence, as naturally as possible, without pausing between words. It was also suggested that participants read sentences individually, pausing briefly between them, as to avoid reading the sentences as if they appeared on a list.

The following pages of the frame included the testing sentences and also additional sentences which were not analyzed in the experiment. These additional sentences were intermixed with the others so participants could not identify which sentences were to be analyzed.

The experiment was monitored for errors. Thus, if a mistake was detected, such as misreading of a word, or the lack of attention as to which was the next sentence to be read, then the participant was requested to read the relevant sentences again.

In each language, for each tonic vowel, there were about ten different words (66 words for Brazilian Portuguese and 63 words for British English). Each speaker read each word once. The total number of words to be analyzed in both languages was 516. Each of the four Brazilian speakers produced a total of 66 utterances; therefore, the total number of words to be analyzed for Portuguese was 264 utterances. Each of the four English speakers produced a total of 63 utterances; therefore, the total number of words to be analyzed for English was 252 utterances.

Recordings were made in the sound-attenuated recording studio at the Universidade Federal de Minas Gerais, Brazil; using a DAT TCD-D8 – Sony and a ECM-T15/t115 microphone. For the English data, recordings were made within a sound proof recording studio at the University of Edinburgh, using a Soundtrac 200B studio Console, a Sony PCM2700A DAT recorder and a AKG Blue Line electric condenser microphone (SE300B amplifier + CK98 mic. capsule).

The data were recorded to Digital Audio Tape at a sampling frequency of 44.1 kHz and a recording level of -10db this level did not fluctuate more or less than 2db. The recordings were then down sampled to computer. Default sampling mode is mono recording (single channel) at 16kHz sample rate, giving a 3 dB bandwidth of 7.88kHz. File format is ESPS, the proprietary file format for the Entropic ESPS/xwaves+ software package. Then these files were converted to .wav files so that they could be opened in a PC. The data were analyzed using PRAAT 4.0.2. © (Boersma & Weenink, 1992-2008) and were previously converted to a 11kHz sample rate which is more appropriate for vowel quality analysis in female speakers. In the following section we indicate how the analysis proceeded.

3.3 Acoustic measurements

Acoustic measurements were made using a temporal window at PRAAT which included the oscilogram, the spectrogram and the formant tracts for the first five formants. The tonic and the post-tonic vowel in each word were analyzed.

In order to know whether the preceding stressed vowel had any influence on the quality of final schwa, both vowels were measured in terms of the first three formants: the stressed vowel and the final unstressed vowel (schwa)[1]. In order to organize the data systematically a 20ms part of the vowel center were selected and the software automatically provided the mean for the selected portion of the vowel. The 20ms portion of the vowel was preferred to a single selected point in order to have more comprehensive data of formant values.

Duration of final schwa was measured selecting as the starting point the beginning of the harmonic pattern, which typically characterizes vowels, and the last observed period in the vowel which was at the end of a sentence, thus followed by silence.

4. Results

The results to be presented considered two analyses. The first one comprises an assessment of descriptive statistics which considered mean values, standard deviation and dispersion graphics for each set of vowels. The second analysis presents ANOVAs results which allowed us to determine the reliability of observed differences.

In the following sections results will be presented separately for each language and then a comparative analysis will be discussed. Results for vowel quality are presented first and then results of duration are given. We will first present the data for Brazilian Portuguese and then the English ones.

4.1 Brazilian Portuguese results

The chart below presents the results of the mean values (by-subjects) with respect to F1 and F2. The two rightmost columns list the results for the schwa, which occurred in the final position of the word. The two leftmost columns list the results for the full vowel which appeared in the stressed position in the word which contained a (s w) pattern, where the schwa occupied the final position.

[1] Even if the third formant was taken into account so as to check the characteristic 1000Hz spacing between formants, all the analysis is based on the first two formants which are the most appropriate to describe vowel quality.

Table 2. Mean values, by-subjects, for Portuguese vowels

Full vowels		schwa	
[a] F1	[a] F2	[ə] F1	[ə] F2
935	1601	625	1615
[i] F1	[i] F2	[ə] F1	[ə] F2
491	2567	601	1709
[u] F1	[u] F2	[ə] F1	[ə] F2
461	858	583	1669
[ɛ] F1	[ɛ] F2	[ə] F1	[ə] F2
725	2336	604	1710
[ɔ] F1	[ɔ] F2	[ə] F1	[ə] F2
725	1071	624	1543
[e] F1	[e] F2	[ə] F1	[ə] F2
554	2513	606	1777
[o] F1	[o] F2	[ə] F1	[ə] F2
557	973	622	1570
Mean of all schwas		609	1656
Standard deviation		15,40254	84,04449

The data in Table 2 indicate that schwa F1 is slightly lower when preceded by a high vowel [u,i] or when preceded by a mid-high vowel [e,o]. However, schwa F1 is lower when preceded by the mid-low vowel [ɛ], than when the schwa is preceded by the mid-high vowels.

It is important to notice that in Brazilian Portuguese a final schwa is a bit more opened (mean of all schwas: 609Hz) than expected in the literature (F1 550Hz for females). The standard deviation is low, showing that there is little variability and, therefore, F1 for a schwa has a target value which is well defined in this position.

F2 values for the schwa are slightly lower when preceded by a back vowel, i.e., when preceded by a vowel with a low F2 such as [o,ɔ] and higher when preceded by a front vowel, i.e., when preceded by a vowel with a high F2 such as [ɛ,e,i]. However, F2 values of a schwa are higher after [u] than after [a], which shows that F2 of [u] has no influence on schwa.

The mean for F2 of all schwas is around what is expected (1656Hz), according to the relevant literature. However, the standard deviation shows greater variability of schwa in terms of F2 than of F1. Therefore, we may conclude that a final schwa is also specified for F2. We have not identified any possible generalization which indicated that the full stressed vowel influenced on the nature of the schwa in Brazilian Portuguese. We argue then that a schwa does have a target of itself in BP.

Consider now Figure 1 that indicates the values for each realization of schwa by each speaker.

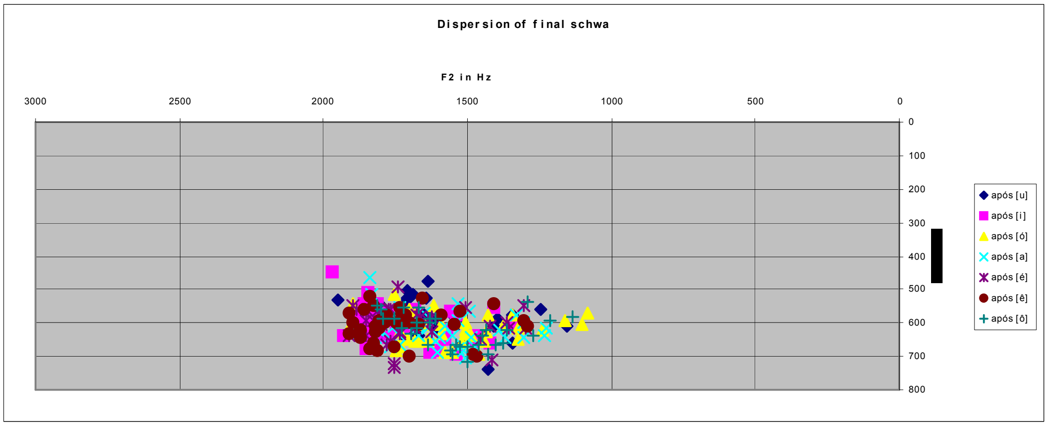

Figure 1. Dispersion of final schwa in Portuguese.

Figure 1 shows that there is greater variability of schwa in terms of F2 than in terms of F1. The difference between the lowest and highest F1 values is about 300Hz while the difference between the lowest and highest F2 values is about 1000Hz. Despite this variability the greatest number of realizations is around the target values which corroborate our claim that a schwa does have a target in BP.

The ANOVA analysis showed that one specific speaker, i.e., Inf.4 (R), influenced the results both for F1 and F2. This may account for some of the variability observed in the results. The tests also showed that only the preceding vowel [u] influenced schwa F1 and the back vowels [o,ɔ] influenced schwa F2. However, the lack of systematic influence of the preceding vowel on the quality of the reduced vowel points to the fact that final schwa has a target. We will now present the duration means for schwa after each vowel for each speaker. Consider data in Table 3.

Table 3. Duration mean values (by-subject) for schwa

Stressed vowel	INF. 1 (F)	INF. 2 (J)	INF. 3 (L)	INF. 4 (R)	(Mean 1)	(SD 1)
[a]	93	126	134	123	119	17,94436
[i]	98	127	150	128	125,75	21,32878
[u]	92	117	147	131	121,75	23,31487
[ɛ]	88	120	139	99	111,5	22,63478
[ɔ]	91	120	115	106	108	12,72792
[e]	104	152	162	141	139,75	25,3295
[o]	120	131	137	142	132,5	9,469248
(Mean 2)	98	127,5714	140,5714	124,2857	122,6071	11,19603
(SD 2)	11,03026	11,81605	14,7293	16,46931		

In the first row in Table 3 (Mean 1) indicates the average duration of a schwa per vowel, by subjects and (SD 1) corresponds to the standard deviation. In the leftmost column (Mean 2) indicates the average duration of schwa per speaker, independently of the quality of the preceding vowel and (SD 2) corresponds to the standard deviation.

When one compares the data for all four speakers, one observes that INF 1 has the lowest mean, INF 3 the highest; and INF 2 and 4 have very similar results. The standard deviation for the four speakers is not so different; therefore, we may conclude that the degree of variability of schwa is not too high.

The same holds for the general mean of approximately 123ms (across vowels and speakers). This result shows that a schwa may be longer than it has been suggested in the literature, since Crosswhite (1999) claims that no schwa is longer than 40ms. In order to verify whether the durational pattern, which showed to be longer than expected, was a characteristic of any schwa in BP, we measured a number of other schwas which occurred in the additional sentences of the experiment (not word/utterance final nor in the accented word of the utterance).

These extra measurements of schwa indicated that other schwas in weak prosodic positions, mainly in structural words, are very short having an average of 30ms. Our results indicate that a schwa is longer in utterance final position (mean 123ms), than in other prosodic ones (average of 30ms).

We have shown that a schwa in BP does have a target although variability may also be observed. It is the lack of generalizations which indicates that the full stressed vowel bears no influence on the nature of the schwa in Brazilian Portuguese. When considering durational values, we observed the lengthening of the final syllable of an utterance with a schwa confirms Cagliari & Abaurre's (1986) claim for BP that final unstressed vowels are longer than other vowels. Our results also challenge Crosswhite's (1999) proposal that a schwa is never longer than 40ms. We will now consider the data for British English.

4.2 British English results

The chart below presents the results of the mean values (by-subjects) with respect to F1 and F2. The two rightmost columns list the results for the schwa, which occurred in the final position of the word. The two leftmost columns list the results for the full vowel which appeared in the stressed position in the word which contained a (s w) pattern, where the schwa occupied the final position.

Table 4. Mean values, by-subjects, for English vowels

Full vowels		schwa	
[ɑː] F1	[ɑː] F2	[ə] F1	[ə] F2
674	1275	614	1516
[iː] F1	[iː] F2	[ə] F1	[ə] F2
369	2707	635	1729
[uː] F1	[uː][2] F2	[ə] F1	[ə] F2
363	2141	623	1599
[æ] F1	[æ] F2	[ə] F1	[ə] F2
932	1624	626	1600
[ɒ] F1	[ɒ] F2	[ə] F1	[ə] F2
568	1160	636	1495
[ɪ] F1	[ɪ] F2	[ə] F1	[ə] F2
450	2318	596	1637
[ɔː] F1	[ɔː] F2	[ə] F1	[ə] F2
452	878	603	1522
Mean of all schwas		619	1585
Standard deviation		15,38397	82,35059

[2] Our results have been corroborated by Paul Boersma (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".

The data in Table 4 indicate that F1 does not seem to be affected by the quality of the preceding vowel in English. This is because no correlation could be found between the preceding vowel and the variability of schwa in our data. In fact, as the standard deviation shows, there is little variability with a schwa. Therefore, we have to assume that F1 value for a schwa is well defined in this position, which suggests that final schwa in English does have a target.

In fact Jones (1976) mentions that final schwas in English, when final in the utterance, are opener (and longer) than other schwas. This can be confirmed by the mean of all schwas in Table 4 which is 619Hz. With regards to F2 one observes that the values are slightly lower when preceded by a back vowel, i.e., when preceded by a vowel with a low F2 such as [ɒ,ɑː,ɔː], and F2 values are higher when preceded by a front vowel, i.e., when preceded by a vowel with a high F2 such as [iː,ɪ,y[3],æ]. The mean for F2 of all schwas is a bit below what was expected (1585Hz), however, that mean shows that final schwa is also specified for F2. This leads to suggest that a schwa has a target in English. Consider now Figure 2 that indicates the values for each realization of schwa by each speaker.

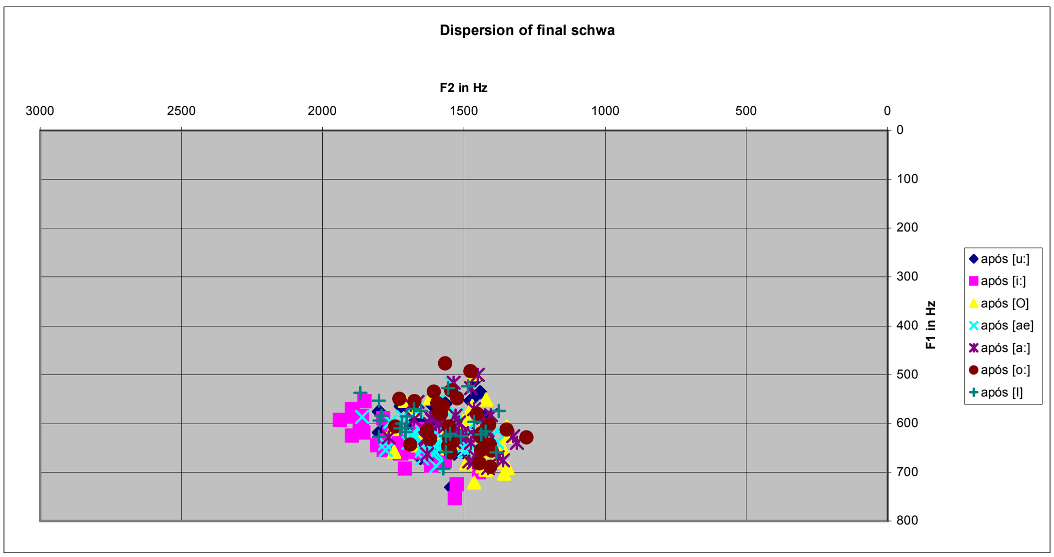

Figure 2. Dispersion of final schwa in English

Figure 2 shows that there is greater variability of schwa in terms of F2 than in terms of F1. The difference between the lowest and highest F1 values is about 300Hz while the difference between the lowest and highest F2 values is about 700Hz. Despite this variability the greatest number of realizations is around the target values.

The ANOVA analysis showed that one specific speaker, i.e., Inf. 3 (R), influenced the results for F1, but no influence of any preceding vowel was verified. F2 was influenced by all speakers due to the fact their production was heterogeneous. The results also showed that the preceding front vowels [æ,ɪ,iː,y] influenced schwa F2. However, the lack of systematic influence of the preceding vowel on the quality of the reduced vowel, i.e., a schwa, points to the fact that final schwa does have a target in English.

We will now present the duration means for schwa after each vowel for each speaker. Consider data in Table 5.

[3] This symbol is used here to better represent the phonetic quality of /u/, i.e., a high **front** rounded vowel.

Table 5. Duration mean values (by-subject) for schwa

Stressed vowel	INF. 1 (F)	INF. 2 (J)	INF. 3 (L)	INF. 4 (R)	(Mean 1)	(SD 1)
[ɑː]	169	187	142	157	163,75	19,03287
[iː]	172	191	156	170	172,25	14,3846
[uː]	182	182	153	160	169,25	14,99722
[æ]	143	170	146	134	148,25	15,37043
[ɒ]	146	159	150	148	150,75	5,737305
[ɪ]	166	187	145	166	166	17,14643
[ɔː]	189	175	151	174	172,25	15,73478
Mean (2)	166,7143	178,7143	149	158,4286	163,2143	10,9253
SD (2)	17,10472	11,38294	4,898979	13,80649		

In the first row in table 5 (Mean 1) indicates the average duration of a schwa per vowel, by subjects and (SD 1) corresponds to the standard deviation. In the leftmost column (Mean 2) indicates the average duration of schwa per speaker, independently of the quality of the preceding vowel and (SD 2) corresponds to the standard deviation.

When one compares the data for all four speakers, one observes that INF 3 has the lowest mean and INF 2 the highest. The means of the four speakers are heterogeneous; however, the standard deviations are low. INF 3 presents the lowest SD across vowels. When considering all the vowels, the most homogeneous results are found for vowel [ɒ] with a SD of 5,737305 by speakers. The general mean is 163ms (across vowels and speakers). In order to know whether this long duration was a constant characteristic of these speakers or a more general result concerning reduced vowels, we measured other schwas which occurred in the additional sentences of the experiment (not word/utterance final nor in the accented word of the utterance). These extra measurements showed that other schwas in weak prosodic positions, mainly in structural words are very short indeed (about 30ms.). In a similar fashion as the results obtained for Brazilian Portuguese our results for British English contradict Crosswhite's proposal that a schwa is never longer than 40ms when it occurs at the end of an utterance.

We will now present a general discussion for both languages with the aim of answering our research questions: a) what are the major quality and quantity characteristics of a final schwa in BE and BP?, b) do adjacent vowels affect the nature of a final schwa? and c) does Crosswhite's (1999) claim that a schwa is never longer than 40ms hold?

5. General discussion and conclusion

In this section we will contrast our results for Brazilian Portuguese and British English. Table 6 shows the major characteristics of vowel quality of a schwa.

Table 6. Vowel quality of final schwa

Means of F1 of all schwas	Means of F2 of all schwas
BP: 609Hz (sd 15.40254)	BP: 1656Hz (sd 84.04449)
RP: 619Hz (sd 15.38397)	RP: 1585Hz (sd 82.35059)

In terms of vowel quality, the mean of all schwas for F1 is very similar in both languages (leftmost column). The mean of all schwas for F2 is just slightly different in each language. General results indicate that a Portuguese final schwa is more anterior than the

English one. This indicates that schwas are very similar in both languages although it appears that it is fine phonetic detail which characterizes the specificity of a schwa in each language (Pierrehumbert, 1999).

Notice also that the difference between the lowest and highest F1 values is about 300Hz in both languages while the difference between the lowest and highest F2 values is about 700Hz in English and 1000Hz in Portuguese. Therefore, Portuguese exhibits greater variability in the horizontal dimension. Some unsystematic influence of the preceding vowel, especially in terms of F2, was observed which did not allow us to figure out any generalization. Thus, despite the observed variability our results indicate that a schwa has a target in both languages. This suggests that an adjacent vowel does not affect the nature of a final schwa in either language contradicting Browman and Goldstein's (1992) proposal.

An evaluation of durational patterns shows a great influence of the prosodic environment on the length of final schwa in both languages: general mean in BP 123ms and 163ms in BE. Therefore, the fact that the analyzed words where accented and final in the utterance was crucial for vowel quantity: a longer than expected schwa was attested. These results confirm Turk & Sawusch's (1997) findings in English that the accentual lengthening affects both the primary stressed vowel and also the following vowel (unstressed). We observe that the same holds for Portuguese offering thus an open invitation to research to be carried out in other languages, in order to understand better the relationship between durational values and the effects of accent.

Finally, durational patterns questions Crosswhite's (1999) claim that a schwa is never longer than 40ms. At least for final utterance position a schwa may be much longer than she has predicted.

Summing up, we have answered the proposed questions of this paper. Regarding the quality and quantity characteristics of a final schwa in BE and BP a contrastive analysis showed that in both languages a schwa presents similar acoustic characteristics both in terms of quality and durational patterns in utterance final position. However, a schwa has its own target in each language. We suggest that it is fine phonetic detail that plays an important role in characterizing formant values of a schwa in either language (Pierrehumbert, 1999).

Concerning the influence of adjacent vowels in the nature of a schwa our results show that it does not hold for utterance final schwas. Thus, Browman and Goldstein (1992) claim that a schwa target is the mean of all English vowels does not hold for this prosodic environment. Thus, the phonetic characteristics of a schwa are similar either as the reduced variant of different vowels - as in English -, or as the reduced variant of a single phoneme - as in Brazilian Portuguese.

Our results also support Bates (1995) proposal that final utterance schwas are different from medial schwas in English. It might be the case that final schwas have an independent target whereas medial schwas may undergo interpolation. Further research on this issue is still necessary.

Finally, durational patterns questioned Crosswhite's (1999) claim that a schwa is never longer than 40ms. At least for utterance final position a schwa may be much longer than she has predicted.

The main conclusion to be drawn in this paper is that the investigation of acoustic properties of segments must take into consideration the prosodic patterns involved. Thus, prosodic properties of reduced vowels may be similar in different languages, although fine phonetic detail may contribute to the phonological interpretation of these vowels.

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