Impact of age in the production of European Portuguese vowels

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Abstract

The elderly population is quickly increasing in the developed countries. However, in European Portuguese (EP) no studies have examined the impact of age-related structural changes in speech acoustics. The purpose of this paper is to analyse the effect of age ([60-70], [71-80] and [81-90]), gender and type of vowel in the acoustic characteristics (fundamental frequency (F0), first formant (F1), second formant (F2) and duration) of the EP vowels. A sample of 78 speakers was selected from the database of elderly speech collected by Microsoft Language Development Center (MLDC) within the Living Usability Lab (LUL) project. It was observed that duration is the only parameter that significantly changes with ageing, being the highest value found in the [81-90] group. Moreover, F0 decreases in females and increases in males with ageing. In general, F1 and F2 decreases with ageing, mainly in females. Comparing the data obtained with the results of previous studies with adult speakers, a trend towards the centralization of vowels with ageing is observed. This investigation is the starting point for a broader study which will allow to analyse the changes in vowels acoustics from childhood to old age in EP.

Index Terms: elderly speech, European Portuguese, oral vowels, acoustic

1. Introduction

Population ageing is one of greatest triumphs of modern society, but also one of its major challenges [1]. More than in other developed countries, the Portuguese population is ageing. Between 1960 and 2011, the percentage of people aged 65 and over increased from 8% to 19% [2, 3]. With ageing, the vocal quality of the speaker modifies due to structural changes in the respiratory, phonatory and articulatory systems [4, 5, 6, 7]. The anatomical and physiological changes in the speech organs are reflected in the decrease of the speaking rate, in the increase of speech pauses and in variations in several acoustic parameters (e.g. F0) [4, 5, 6]. Due to these alterations, the current automatic speech recognition (ASR) systems do not yet work well with elderly speech [8, 9]. This is because the acoustic models needed to recognise speech are usually trained using speech collected from younger speakers [8, 9]. Consequently, elderly people have more difficulties in the interaction with computers, which represents a barrier to their access to new technologies [9].

Several studies have analysed the effects of age in the acoustic characteristics of speech [5, 6, 7]. Most research report that F0 increases in males and decreases in females with ageing [5, 10, 11]. In what concerns F1 and F2, some referred the lowering of these parameters [6, 7, 12] and there also seems to be a trend towards vowel centralisation (or reduction) in seniors [11, 13, 14]. Vocal ageing also implies a decrease in the number of syllables and phonemes per second, which leads to the increase of segment duration [5]. For European Portuguese (EP), there is almost no data on the acoustic correlates of ageing, except [8]. The few available studies are focused on the acoustic characteristics of the oral vowels produced by young adults [15, 16] and children [17].

Only a deeper knowledge of how speech changes with age in a given language will make it possible to develop speech technologies more adequate to the end user. Consequently, this will allow to combat the isolation of the elderly and to allow them to remain more independent, productive, and socially engaged [9]. The aim of this paper is to study the acoustic changes with age, specifically the F0, formant frequencies and the duration of oral vowels produced by EP speakers over 60 years of age.

This paper is organized as follows: Section 2 describes the adopted method, Sections 3 presents the obtained results, Section 4 discusses the impact of age in the acoustic parameters and lastly, Section 5 presents the conclusions and the future work.

2. Method

2.1. Speech Material

The speech material used was part of speech data obtained through the campaign “Doar a Voz”. It was conducted within the Living Usability Lab (LUL) project [9]. The aim of this campaign was to collect speech data of elderly Portuguese speakers over 60, in order to contribute to the improvement of speech recognition technology for these users [9].

The corpus included phonetically rich sentences as well as common types of prompts used in speech-driven applications and also prompts specific to the speech-driven applications developed in the LUL project [9]. Each speaker was asked to utter a set of 160 prompts selected across the 14 prompt categories present in the corpus. This resulted in the recording of approximately 20-minute sessions and in around 6-7 minutes of pure speech. In total, about 194 hours of data were recorded, of which almost 92 hours are pure speech of 1011 elderly speakers

[9].

2.1.1. *Corpus*

For this study, only the EP oral vowels ([i], [e], [ɛ], [a], [o], [ɔ] and [u]) in stressed position were selected from the abovementioned database. Each vowel was produced as the first vowel in a disyllabic CVCV sequence (e.g. "casa", *house*), where C represents voiced and voiceless stop consonants ([p], [t], [k], [b], [d] and [g]) and voiced and voiceless fricative consonants ([f], [s], [ʃ], [v], [z] and [ʒ]).

An attempt was made to remove the words that arose in an isolated context or in the beginning and end of sentences, due to the impact of word position in the values of F0, F1, F2 and in the duration of vowels under analysis.

2.2. Speakers

From all the data of the campaign "Doar a Voz", a selection was made for this study. Since the centre of Portugal is the most representative region in the database [9], only the speakers of this region were selected. The speakers who did not complete the recording of 160 prompts and whose speech recordings had poor quality were excluded from this study. Also, each speaker had to have produced at least one valid word selected from the corpus. Thus, 491 valid speakers were obtained, 132 male and 359 female.

A random sample of 14 speakers by gender and age group ([60-70], [71-80] and [81-90]) was selected for this study. However, for the male group [81-90] it was only possible to obtain 8 speakers. This resulted in a total of 78 speakers.

2.3. Speech Analysis

Each vowel and flanking consonants were manually segmented and labelled, over the digitized sound wave, by using the software Praat [18].

The F0 of the 7 vowels was estimated with the cross-correlation method. The median F0 was taken of the central 40% of each vowel. The pitch range for the analysis was set to 60–400 Hz in males and 120–400 Hz in females.

To extract the values of F1 and F2, a procedure to optimize the formant ceiling for a certain vowel of a certain speaker was applied, adapted from [15] and already applied to children [17]. The first two formants were determined 201 times for each vowel, namely for all ceilings between 4500 and 6500 Hz in steps of 10 Hz (for female) or for all ceilings between 4000 and 6000 Hz in steps of 10 Hz (for male). The chosen ceiling was the one that yielded the lowest variation (for more details see [15]). Thus, for each vowel produced by each speaker there is only one "optimal ceiling".

The total duration was computed from the label files that contained the beginning and the end points of each vowel.

2.4. Statistical Analysis

The statistical analysis was conducted with the SPSS software package (SPSS 21.0 - SPSS Inc., Chicago, IL, USA). The values of F0, F1, F2 and duration were calculated for all productions, and subsequently, the median of repetitions was performed for each vowel and speaker.

The analysed dataset presented missing data (less than 20.0% for all vowels, except the vowel [e] with 23.1%), because there were speakers who did not produce at least one of each vowel. Its missing pattern was classified as missing completely at random (MCAR) and confirmed with the Little MCAR test (the pattern of missing values does not depend on the data values) [19, 20, 21]. An expectation-maximization (EM) imputation method was used to fill the miss missing values [19, 20]. Of notice, after the imputation of the missing values, the dataset characteristics (mean, standard deviation (SD), maximum, and minimum) were identical to the original data.

For each dependent variable (F0, F1, F2, and duration), a three-way mixed analysis of variance (ANOVA) was applied, with vowel as a within-subject factor and with gender and age as between-subject factors. The ANOVA assumptions of residual normality and homogeneity of variance were validated. In what concerns the sphericity assumption, the Epsilon Huynh-Feldt correction was used. In all statistical analysis, the level of significance was $p<0.05$.

3. Results

The mean and SD of the 4 features analysed in this section are presented in Table 1, according to age and gender. Each value represents the mean of the 7 oral vowels under analysis.

Table 1: *Mean and SD of F0, F1, F2 and duration by gender and age.*

Age	[60-70]		[71-80]		[81-90]	
Gender	♀ (N=14)	♂ (N=14)	♀ (N=14)	♂ (N=14)	♀ (N=14)	♂ (N=8)
F0 (Hz)	200.4±22.6	129.5±34.5	189.9±25.2	139.3±21.9	187.6±28.0	140.3±30.1
F1 (Hz)	561.4±41.8	455.2±23.1	548.6±30.0	479.6±28.7	523.2±38.7	463.5±26.3
F2 (Hz)	1682.0±89.9	1449.1±85.6	1695.9±81.9	1435.8±75.0	1669.4±88.4	1423.7±119.1
Dur. (ms)	99.3±17.6	93.3±18.6	98.8±18.9	89.3±16.7	114.7±17.1	106.9±22.4

3.1. Fundamental Frequency

Figure 1 presents the mean of F0 for each EP vowel in terms of age and gender.

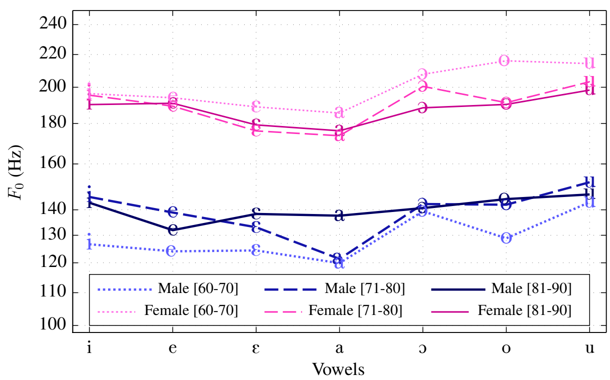


Figure 1: *Mean of F0 for each vowel (determined with the data in logarithmic values) and age group.*

As can be seen in Figure 1, female speakers present, as expected, higher F0 values (192.7 Hz ± 27.2) than male speakers (136.4 Hz ± 28.1). This difference is reported in literature, and as consequence of the differences in vocal fold length and weight between the female and male gender [15]. ANOVA shows that this effect of gender on F0 values is statistically significant ($F(1;72)=80.1$; $p<0.001$).

The effect of vowel is also statistically significant ($F(5.0;358.2)=16.3$; $p<0.001$). As illustrated in Figure 1, the lowest mean value of F0 corresponds to the central low vowel

[a] (153.5 Hz ± 40.2), followed by the front vowels ([ɛ] (158.1 Hz ± 38.1)< [e] (163.8 Hz ± 44.1)< [i] (167.9 Hz ± 43.3) and finally, the back vowels ([o] (170.7 Hz ± 46.1)< [ɔ] (172.1 Hz ± 42.0)< [u] (178.5 Hz ± 42.6)). Considering only the 3 vowels [a], [i] e [u], it can be observed that the high vowels [i] and [u] have a higher F0 than the low vowel [a], which is related to the intrinsic F0 effect of vowels [22, 23]. This effect has been reported as occurring in different languages [22]. In addition, the front vowels present a lower F0 than back vowels. A similar effect was also found in studies on English [22], EP and Brazilian Portuguese (BP) [15].

Regarding age, as shown in Table 1 and in Figure 1, the highest mean value of F0 was observed for the younger female group [60-70]. The opposite tendency was observed for the males, whereas the lowest mean value of F0 was observed for the younger male group [60-70]. However, no statistical differences were found in age (F(2;72)=0.0; p=0.993).

3.2. Formant Frequencies

Figure 2 depicts the mean F1 and F2 values for each group of speakers for the 7 vowels. Figure 3 shows the vowel space of female speakers by age.

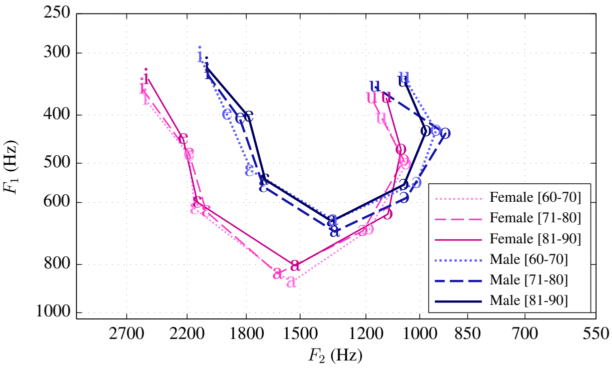


Figure 2: *F1/F2 chart according to age and gender (each symbol represents the geometric mean of the median values of F1 and F2).*

As shown in Table 1, female speakers present significant higher F1 values (544.4 Hz ± 32.5) than male speakers (466.1 Hz ± 33.7), as expected [24]. The mean value of F1 is higher for the low vowel [a] (757.5 Hz ± 110.5), followed by the lower mid vowels [ɔ] (618.5 Hz ± 82.4) and [ɛ] (579.0 Hz ± 63.1); and then, by the higher mid vowels [o] (462.7 Hz ± 49.5) and [e] (439.0 Hz ± 47.9), and lastly by the high vowels [u] (364.1 Hz ± 44.1) and [i] (338.4 Hz ± 38.5). Thus, the main determiner of the F1 value is the vowel height. Therefore, it can be said that the F1 values inversely vary to the height of the tongue [15, 25]. It is also important to mention that the effect of gender (F(1;72)=108.0; p<0.001) and vowel (F(3.8;272.5)=1089.0; p<0.001) is statistically significant.

For F1, ANOVA indicates that there were no significant age differences (F(2;72)=2.5; p=0.092). However, there are significant interactions between age and gender (F(2;72)=3.6; p=0.031). F1 continuously decreases with ageing in females (see Figure 3). Whereas in males, F1 increases between [60-70] and [71-80] age groups and decreases in the elderly group [81-90]. This indicates that the pattern of variation of the F1 values with ageing differs between female and male speakers.

As presented in Figure 2, the highest mean value of F2 is presented by the female speakers (1682.5 Hz ± 88.3) in comparison to the male speakers (1436.2 Hz ± 91.4). The differences between genders are statistically significant (F(1;72)=145.2; p<0.001). Similarly to F1, the F2 values are also related to the different dimensions of the vocal tract between female and male speakers [24].

The vowel effect on F2 is statistically significant (F(3.0;216.1)=1100.7; p<0.001). The mean value of F2 is higher for vowel [i] (2322.4 Hz ± 296.8) followed by [e] (2042.4 Hz ± 259.2), [ɛ] (1931.8 Hz ± 252.6), [a] (1459.8 Hz ± 151.0), [u] (1121.4 Hz ± 162.2), [ɔ] (1107.1 Hz ± 120.8) and [o] (1003.4 Hz ± 141.4). This suggests that F2 varies with the position of the tongue in the anteroposterior dimension [25].

No statistical differences were found in age (F(2;72)=0.4; p=0.705). However, in can be seen in Table 1 that F2 slightly decreases with ageing in males, whereas in females it increases between [60-70] and [71-80] age groups and decreases in the elderly group [81-90]. The later presents the lowest F2 values.

3.3. Duration

The mean duration of each vowel in terms of age and gender is depicted in Figure 4.

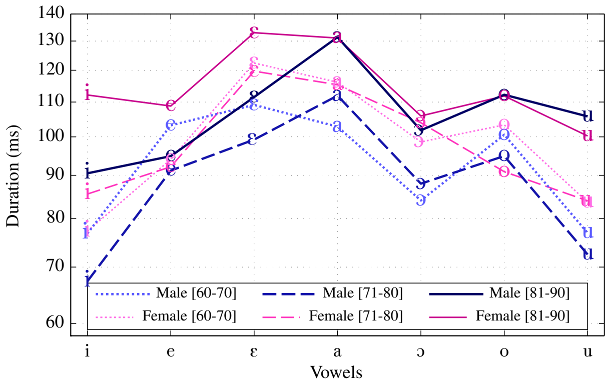
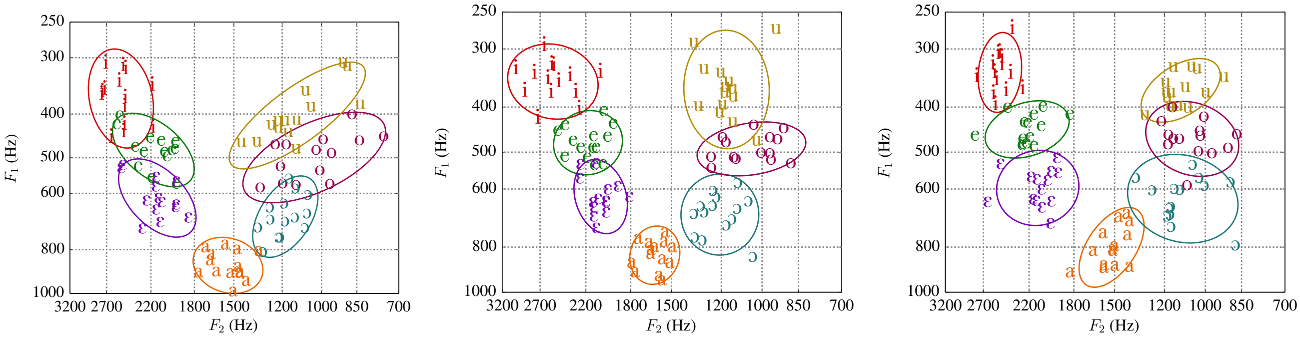


Figure 4: *Mean duration of vowels (determined with the data in logarithmic values) for each speaker group.*

Speakers from the group [81-90] display the longest vowel durations (110.8 ms ± 19.0). Moreover, the younger groups present similar values ([60-70] - 96.3 ms ± 18.3; [71-80] - 94.0 ms ± 18.3), which means that the duration of vowels increases with ageing. So, the effect of age is statistically significant (F(2;72)=5.5; p=0.006).

The effect of vowel on the mean value of the duration is also statistically significant (F(5.5;395.7)=24.7; p<0.001). The pattern of vowel duration is observed as follows: [i] (84.5 ms ± 26.4)< [u] (85.7 ms ± 27.5)< [ɔ] (96.7 ms ± 31.7)< [e] (97.6 ms ± 25.4)< [o] (101.5 ms ± 34.1)< [ɛ] (116.2 ms ± 25.9)< [a] (117.1 ms ± 28.3). This result is consistent with the literature, where it is referred that open vowels require more jaw lowering, hence more time to be produced, than closed vowels [15, 16]. This effect is called intrinsic vowel duration [15].

It can also be observed that female speakers present higher vowel durations (104.3 ms ± 18.3) than male speakers (96.5 ms ± 18.7). However, ANOVA indicates there were no significant age differences (F(1;72)=3.4; p=0.070). This trend was observed in Portuguese (EP and BP) [15, 17] as well as in English [26]. This gender effect may have a socio-phonetic origin or a physiological one [15]. However, in [27] no significant differences in the duration of vowels according to gender in BP were found.



(a) (b) (c)

Figure 3: *The vowel space of females aged (a) [60-70], (b) [71-80] and (c) [81-90].*

4. Discussion

The parameter that is most affected by ageing is the duration of vowels, which increases significantly with ageing [5, 28, 29]. This probably occurs as a consequence of the decrease in the speech rate. According to [8], in the ASR point of view, the most important characteristics of elderly speech are related to pausing, speech rate, average phone duration, and percentage of long phones. The increase in the duration of the segments produced by elderly speakers may be related to the slowing of the nerve conduction velocity and with the changes verified in the respiratory and central nervous systems [6].

It was observed that F0 tends to slightly decrease in females and increase in males with the ageing. This is consistent with the data available for other languages [5, 11, 30, 31, 32]. In the only previous study on EP, where the F0 of young adults and elderly speakers is compared [8], a significant decrease of F0 is referred to in females, whereas in males no changes were observed. The decrease of F0 in females has been attributed to the vocal fold edema resulting from endocrinological changes after menopause [33]; however, the increase of F0 in males may be related to the decrease in the vocal fold mass due to atrophy, tissue stiffening and the thinning of the vocal folds with ageing [33].

Contrasting with what was observed for males, in females F1 continuously decreases with ageing [7, 12, 34, 35, 36], probably due to the lengthening of the vocal tract with ageing [7, 12, 34, 36]. For EP, [8] observed an increase of F1 in the vowels produced by the elderly compared to the ones produced by adult speakers. However, considering only the elderly, there were no significant changes in F1 with ageing. In general, F2 tends to slightly decrease in both genders, as a result of the lengthening of the vocal tract with ageing, and this was reported in other works [7, 12, 34].

Comparing the data obtained in this study for the elderly with the results obtained by [15] for EP adult speakers (cf. Figure 5), it can be concluded that the elderly have higher F1 values than adults for all vowels in both genders. The values of F2 tend to decrease in front vowels and increase in back vowels with ageing, for all vowels and in both genders. These results show a trend towards the centralization of vowels with ageing [13, 14].

5. Conclusions

This article presents acoustic data of oral vowels produced by EP elderly speakers, namely F0, F1, F2 and duration. This study was only possible due to the availability of the database of elderly speech by the Microsoft Language Development Center (MLDC). It allowed a first acoustic characterization of the vowels produced by the EP elderly. These results can now be used to improve the performance of ASR systems for the elderly. This will make the access of the elderly to new technologies easier. A deeper knowledge of the elderly speech is also essential for speech therapy, to allow a better and more effective intervention.

This study is the starting point for a broader study, considering a higher number of speakers and age groups, which will allow the analysis of the changes of the vowel acoustic parameters from childhood to old age in EP speakers. Additionally, it would also be interesting to ally acoustic analysis with other techniques, such as ultrasonography, in order to study the relation between the acoustic and the articulatory changes during ageing.

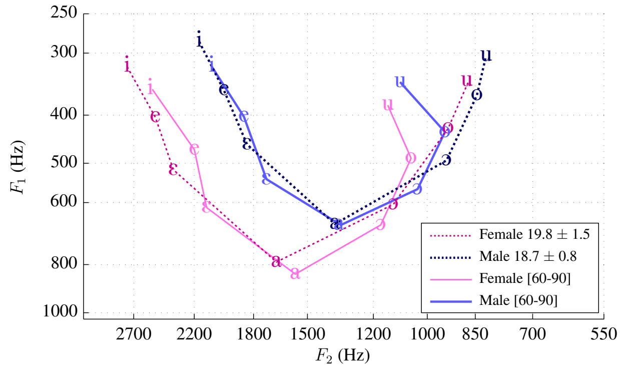


Figure 5: *F1/F2 chart that compares elderly speakers with adults (adapted from [15]) .*

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