A Comprehensive Analysis of Age and Gender Effects in European Portuguese Oral Vowels

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Summary: The knowledge about the age effects in speech acoustics is still disperse and incomplete. This study extends the analyses of the effects of age and gender on acoustics of European Portuguese (EP) oral vowels, in order to complement initial studies with limited sets of acoustic parameters, and to further investigate unclear or inconsistent results. A database of EP vowels produced by a group of 113 adults, aged between 35 and 97, was used. Duration, fundamental frequency (f0), formant frequencies (F1 to F3), and a selection of vowel space metrics (F1 and F2 range ratios, vowel articulation index [VAI] and formant centralization ratio [FCR]) were analyzed. To avoid the arguable division into age groups, the analyses considered age as a continuous variable. The most relevant age-related results included: vowel duration increase in both genders; a general tendency to formant frequencies decrease for females; changes that were consistent with vowel centralization for males, confirmed by the vowel space acoustic indexes; and no evidence of F3 decrease with age, in both genders. This study has contributed to knowledge on aging speech, providing new information for an additional language. The results corroborated that acoustic characteristics of speech change with age and present different patterns between genders.
Key Words: Aging voice−Acoustic−Oral vowel−European Portuguese.

INTRODUCTION

According to the World Health Organization[1,2] the number of people aged over 65 is increasing as a result of longer life expectancy and also of declining fertility rates. Portugal is one of the developed countries with the highest rate of older population (between 1970 and 2018, the percentage of people aged 65 and over increased from 9.7% to 21.8%).[3,4]

Aging involves changes at physiological, cognitive, psychological, and social levels. Age-related changes take place in different tissues and organs, and the vocal system is no exception.[5] Moreover there are substantial gender differences in the extent and timing of the aging process.[5−8]

The anatomical and physiological changes in the speech organs (eg, decreased lung capacity; ossification and calcification of the laryngeal cartilages and vocal fold atrophy)[5,8,9] are reflected in the variation of several acoustic parameters, namely in the decrease of the speaking rate, in the increase of speech pauses, in the variation of the fundamental frequency (f0), in the pattern changes of the formant frequencies and in the increase jitter and shimmer, among others.[8,9]

Unlike other languages, in which age-related speech variations have been widely studied since the 1960s,[8] on what concerns European Portuguese (EP) there are only a few studies about segmental and supra-segmental changes motivated by aging.[10−13] For these reasons, the purpose of this study is to extend the analyses of the age effects on duration, f0 and formant frequencies (F1, F2, and F3) for all EP oral vowels produced by a large group of healthy speakers. A more in-depth analysis of the age effect on each vowel was performed, using the database created for the authors initial studies.[10]

To complement the initial inconclusive results obtained with vowel space area (VSA), which is a well established acoustic metric,[14−18] other acoustic indexes were adopted to further investigate age and gender effects. The first formant range ratio (F1RR) and second formant range ratio (F2RR) were selected to model possible reduction in the articulatory capability of speakers.[19−21] Vowel articulation index (VAI) and formant centralization ratio (FCR) were included to maximize sensitivity to vowel formant centralization and minimize sensitivity to interspeaker variability.[22,23] The general assumption is that young speakers have a better articulation capability than older speakers, thus young adults are able to move their tongue with greater amplitudes and they are able to hold it longer in certain positions.[24,25]

The present study extends the analyses of previous researches[10,11] by including F3 values and different vowel space metrics from Portuguese adults covering the age range of 35−97, which is essential to provide a more complete view of age-related changes in EP vowel acoustics.

As novelty this study considers age as a continuous variable in the analysis avoiding the effects of arbitrary age groups division. Thus, age-related changes in vowel acoustics are analyzed using multiple linear regression.

Since there is a paucity of literature on EP vowel acoustics and the available data were collected from a small number of speakers,[11,26−28] this study also provides valuable insights to an accurate description of these sounds.

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The natural process of aging has a significant impact on the acoustic measurements of speakers' vocal output.[29] Accordingly, it is very important that voice clinicians be aware of such effects and use discretion when making acoustic diagnoses and clinical judgments of elderly clients' voices.[29] A deeper knowledge of how speech changes with age is also essential for the development of automatic speech recognition systems suitable for elderly's voices (eg, personalized reading aids and voice prostheses),[30] for the provision of information for biometric recognition[31] and forensics, and for clinical assessment and treatment of speech disorders.[32,33]

BACKGROUND

Numerous studies have evaluated the effects of aging on the acoustic properties of speech.[6,8,30] Most of them have focused on f0 and have shown a decrease with aging in women[8,34−39]; for men there is less agreement among researches, with some studies indicating that f0 significantly decreases above 60,[30,40] and others suggesting an f0 drop in men over the age range 30−50 and then an increase in f0 in older age.[6−8,35−38,41,42]

Other studies have reported on age-related changes to formants (mostly F1 and F2, neglecting higher formants), particularly in the production of vowels. The conclusions across studies are inconsistent, with some studies showing an age-dependent formant frequency lowering[9,29,43−46] and others reporting no changes in formant frequencies.[47,48] In some cases the formant frequencies varied with vowel and a gender-vowel interaction was found.[8,35] In addition, some studies have referred a centralization of the vowel space in older speakers (which should result in movement to the centroid of formant space).[8,24,25,38,49]

It has often been noted that older adults use slower speaking rates,[6,8,50] that is, vocal aging implies a decrease in the number of syllables and phonemes per second, which leads to the increase of segment duration.[6,8,47,51−53]

The few data available for the EP have indicated an f0 drop of 20 Hz with advanced age in women, while for men no age-related changes were observed, when comparing young adults (aged 19−30) with two groups of older adults (aged 60−75 and over 75).[12] Another study[13] reported a trend of decrease in f0 with aging in both genders (comparing speakers aged between [19−40] and [41−67]) in different speech tasks, but those changes were not statistically significant. In addition, Pellegrini et al[12] showed a greater centralization of the vowel space in younger speakers, and a significant increase in vowels duration with age for both genders.

Our previous studies[10,11] and Pellegrini et al,[12] presented consistent results concerning vowel duration, showing a significantly increase with aging. On the subject of f0 and formant frequencies, the results were not consistent and seemed to be different among vowels.[10,11]

Given that those previous researches used different corpora and analysis procedures, and focused on different acoustic parameters, it is hard at this time to draw solid conclusions on the effects of age and gender on each EP oral vowel. In general, only the decrease in vowel duration in both genders and a trend for f0 decrease in women with aging seems to be more consensual.[10−12]

METHOD

This cross-sectional study was approved by the Ethics Committee Centro Hospitalar São João/ Faculty of Medicine, University of Porto, Portugal (approval number N38/18), and all participants agreed and signed the consent form before participating in the study.

Participants

A total of 113 native Portuguese speakers (56 men and 57 women), from the central region of Portugal, aged between 35 and 97, participated in this study. To ensure an equitable distribution of participants, the following age groups were covered: [35−49] (15 men, 15 women), [50−64] (15 men, 15 women), [65−79] (15 men, 16 women), and ≥80 (11 men, 11 women). A 80-year-old woman was excluded during the acoustic data analysis.

Participants were recruited through personal contacts and through snowball technique in the community, and in Senior Universities from the center of Portugal, and also in the University of Aveiro. Each participant completed a written questionnaire to gather information about socio-demographic characteristics, medical and voice related history, smoking habits, alcohol, water and caffeine consumption, support device needs and environmental conditions. For more details about the study design see Albuquerque et al.[10]

Corpus

The speech corpus consisted of 36 words, with the EP vowels [i], [e], [ɛ], [a], [o], [ɔ], [u] in stressed position and the vowels [ɨ] and [ɐ] in unstressed position. Each vowel was produced in a disyllabic sequence, mostly C**V**.CV (C-consonant, V-vowel) (eg, "pato", *duck*), where C was a voiced/ voiceless stop consonant ([p], [t], [k], [b], [d], [g]) or a voiced/ voiceless fricative consonant ([f], [s], [ʃ], [v], [z], [ʒ]). The list of 36 words used in this study is listed in Table 1.

The speech stimuli were carefully chosen to allow easy and accurate formant measure since the vowel context is restricted to stop and fricative consonants. The corpus was also designed to collect data over the life span. So, the words were therefore chosen to be familiar to all ages, and also, easily represented by images (to avoid the interference of reading abilities in the words production).

A pilot naming study was carried out for the selection of these images. Sixty-three pictures were selected from color pictograms of Palao[54] and presented to a group of 10 participants (5 males and 5 females), ranging from 28 to 86. The results indicated that adult participants were able to properly name most of the pictures (percentage of accuracy equal or higher than 70% excepted for 6 images) (see Table 1).

TABLE 1.
List of Words Per Vowel (International Phonetic Alphabet)

Oral vowels		Words			
Stressed	[i]	['fitɐ] (*ribbon*)	['biku] (*beak*)	['figu] (*fig*)	['pizɐ]* (*pizza*)
	[e]	['seʃtɐ] (*basket*)	['dedu] (*finger*)	['pezu] (*weight*)	['zebɾɐ] (*zebra*)
	[ɛ]	['sɛtɨ] (*seven*)	['tɛtu] (*ceiling*)	['sɛtɐ] (*arrow*)	['ʃɛkɨ] (*check*)
	[a]	['ʃavɨ] (*key*)	['fakɐ] (*knife*)	['gatu] (*cat*)	['patu] (*duck*)
	[ɔ]	['kɔpu] (*glass*)	['bɔtɐ] (*boot*)	['fɔkɐ] (*seal*)	['tɔʃɐ]* (*torch*)
	[o]	['bokɐ] (*mouth*)	['koku] (*coconut*)	['posu] (*well*)	['gotɐʃ] (*drops*)
	[u]	['ʃuvɐ] (*rain*)	['ʃupɐ]* (*lollipop*)	['kubu]* (*cube*)	['ʒubɐ]* (*mane*)
Unstressed	[ɐ]	[kɐ'fɛ] (*coffee*)	[ʃɐ'pɛw] (*hat*)	[pɐ'tĩʃ] (*rollerblades*)	[pɐ'pɛɫ] (*paper*)
	[ɨ]	[bɨ'beɾ] (*to drink*)	[dɨ'daɫ] (*thimble*)	[pɨ'daɫ] (*pedal*)	[pɨʃ'kaɾ]* (*to fish*)

* The pictogram of this word presented a naming percentage of accuracy lower than 70%.

However, these stimuli remained in the study due to the difficulty in finding alternative words that met the previously defined criteria. The stimuli were embedded in a carrier sentence "Diga... por favor" (*"Say... please"*).

Recording protocol

Recordings took place in quiet rooms in several institutions using an AKG condenser microphone and USB external soundcard (PreSonus), with a sampling rate of 44,100 Hz. The participants were seated at a table and the microphone was adjusted to each participant and positioned at an approximately 15−20 cm distance from the mouth.

The sentences were randomized and presented on the computer screen with software system SpeechRecorder[55,56] using pictures together with the orthographic word. Participants were asked to read the sentences at comfortable pitch and loudness level, after familiarizing themselves with the structure of the sentences. Additionally, they could take a break at any time they wanted and each speaker attended a single recording session. Each carrier sentence was repeated three times. Thus, each participant produced 12 repetitions of each vowel, in a total of 108 productions by speaker (113 participants x 36 words x 3 repetitions = 12 204 recordings), and needed approx. 15 minutes to complete this task. The same researcher was present in all recording sessions.

Segmentation

The recorded data was first automatically segmented at word and phoneme level using WebMAUS General for Portuguese language (PT)[57,58] and then imported into Praat speech analysis software,[59] so that four trained analyzers could manually check the accuracy of the vowel boundaries. The start and end points of the vowel were determined by finding the first and last periods that had considerable amplitude and whose shape resembled that of more central periods, with both points of the selection chosen to be at a positive zero crossing of the waveform.

A total of 736 recordings were discarded (approximately 6% of trials) due to problems with the recordings (eg, clipping, noise, misread, hoarseness or vocal fry) or vowel reduction (vowel [ɨ] was the most deleted vowel (359 vowels [ɨ] corresponding to 26.7%), mostly in the context of "pescar" ([pɨʃ'kaɾ] - *to fish*).

Acoustic measurements

Acoustic parameters (f0 and formant frequencies) were automatically extracted from the central 40% of each target vowel using Praat scripts.[26] Median f0 value of the vowels was estimated with the cross-correlation algorithm.[26] The pitch range for the analysis was set to 60−400 Hz for men and 120−400 Hz for women. If the analysis failed on any of the speaker's vowel tokens, that token was excluded (31 vowels, most of them produced by an 80-year-old woman, which we decided to exclude from all the analysis).

Burg-LPC algorithm, as provided by Praat, was used to compile values for F1, F2, and F3. A procedure (adapted from Escudero et al,[26]) was applied to optimize the formant ceiling for a certain vowel of a certain speaker. The first three formants were determined 201 times for each vowel, for all ceilings between 4500 and 6500 Hz for female and between 4000 and 6000 Hz for male, in steps of 10 Hz. The chosen ceiling was the one that yielded the lowest variation. Thus, for each vowel produced by each speaker there is only one "optimal ceiling" (for more details see Escudero et al.[26]).

The duration measurements were computed from the label files with reference to the beginning and the ending points of each vowel. Vowels with duration values shorter than 20 ms were excluded (8 vowels), and outliers that exceeded 2.5 standard deviations from the mean for particular speaker by f0 and from their gender x vowel mean by F1 and F2 were also excluded from this analysis.[35,60] In this study, the measurements for duration, f0, F1−F3 were manually checked for possible extraction errors and these procedures yielded in 695 outliers removed (nearly 1.5% of the total data).

The F1RR is defined as the ratio of the F1 of the low vowel [a] and the (geometric) average F1 of the high vowels

[i] and [u] by speaker.[19,20,26] The F2RR is computed as the ratio of the F2 of vowel [i] and the F2 of the vowel [u] for each speaker.[19,20,23,26]

The VAI is calculated using the formula:

$$VAI = (F2[i] + F1[a])/(F2[u] + F2[a] + F1[u] + F1[i]), \quad (1)$$

and its inverse, the FCR, is calculated as:

$$FCR = (F2[u] + F2[a] + F1[u] + F1[i])/(F2[i] + F1[a]) \quad (2)$$

[18,22,23] Note that the F1 and F2 coordinates of the EP corner vowels [a], [i] and [u] were used to calculate the VAI and FCR metrics, so the FCR should increase with centralization and decrease with vowel expansion, and the opposite for VAI.[22,23]

Reliability in vowel segmentation

To determine inter- and intra-rater reliability of the measures, 36 textgrids of each analyzer (1 textgrid randomly selected from each word) were re-labeled for all analyzers. So, 144 (1.2%) of a total of 12 204 textgrids (113 participants * 36 stimulus * 3 repetitions) were manually relabelled for reliability by the four judges. The scripts to obtain vowel duration and formant frequencies were then re-administered.

Inter and intrarater reliability was assessed using the intraclass correlation coefficient (ICC) and two-way mixed model (the raters were considered fixed) with an absolute agreement definition.

Reliability among the raters was considered excellent, with ICC values > 0.952 for all vowels/ acoustic parameters (duration, f0, F1, F2, F3), except F1 of [ɨ] where ICC was 0.846, but still considered good reliability.[61]

To assess intra-rater reliability, a random sample of 36 textgrids (one of each stimuli) was manually rechecked by the same rater. Again, reliability was excellent with ICC values > 0.909 for all vowels/ acoustic parameters.[61]

Statistical analysis

The statistical analysis was conducted with the SPSS software package (SPSS 25.0 - SPSS Inc., Chicago, Illinois). The values of f0, F1, F2, and F3 were computed for all productions, and subsequently, the median of repetitions was performed for each vowel and speaker. Descriptive data reported the mean for age group.

For each vowel and acoustic parameter (duration, f0, F1, F2, and F3), a multiple linear regression was conducted with the following explanatory variables: age (continuous), gender (male: reference group, female), and the interaction between age and gender. The model presented by the software considered age and gender (female) redundant (presenting instead the interactions "male*age" and "female*age") and no values are presented for those (independent) variables. Also, a multiple linear regression was conducted with the same explanatory variables for F1RR, F2RR, VAI, FCR, and for mean values of all vowels by acoustic parameter. The regression coefficients and the correspondent 95% IC were calculated. The residuals Normality was tested (Kolmogorov-Smirnov Test) and verified with the visual inspection of the Q-Q plot.

RESULTS

This section presents the detailed results of the acoustic measurements and statistical analysis aimed at investigating differences by age and gender for f0 and formant frequencies of all vowels. To avoid effects of arbitrary age groups division, correlation and regresssion analyses for all acoustic parameters were performed. To complement the results of the linear regression and also to provide normative acoustic data for speakers of EP, average values for all acoustic parameters by age group and vowel, separately for each gender are presented in Appendices (Tables A1, B1 and C1).

Vowel duration increased with age

Scatterplot and regression results for the duration are presented in Figure 1, and show an increase of mean duration for all vowels with age, for both genders. For females duration increased from approximately 100 ms to more than 140 ms between the ages 35 and 100; the increase was lower for males, only reaching 130 ms at the age of 100.

The multiple linear regression revealed a significant effect of age in both genders, for most vowels and for the mean of all vowels (males: B = 0.451; P = 0.004; IC95% = [0.144;0.759]; females: B = 0.730; $P < 0.001$; IC95% = [0.427;1.033]). Only vowel [ɨ] in both men (B = 0.138; P = 0.258; IC95% = [–0.103;0.379]) and women (B = 0.183; P = 0.129; IC95% = [–0.054;0.421]) did not seem significantly affected by age. There was not a significant effect of gender, with men (114.4 ms ± 19.0) and women (118.3 ms ± 21.2) producing vowels with similar mean duration (B = 12.754; P = 0.362; IC95% = [–14.854;40.362]).

Age effects in f0 were gender dependent

The scatterplot of f0 mean vowels is presented in Figure 2 and shows that mean f0 tended to decrease with age in women and slightly increase in men. Regression lines indicated a decrease for females of about 25 Hz between the ages 35 and 100, and an increase around 10 Hz for males between the same ages.

Regression model revealed a main effect of gender ($B = -88.482; P < 0.001; IC95\% = [-128.000;-48.964]$), since male speakers had significantly lower f0 (138.7 Hz ± 27.6) compared to female speakers (193.3 Hz ± 23.9), as expected. The effects of age in both genders were not significant for the majority of the vowels, except for the unstressed vowels in females ([ɨ]: $B = -0.766; P = 0.003; IC95\% = [-1.271;-0.262]$; [ɐ]: $B = -0.954; P < 0.001; IC95\% = [-1.434;-0.475]$). In these vowels f0 decreased very sharply with age.

As illustrated in Figure 3, which was drawn using equations of linear regression (of all vowels by gender and f0)

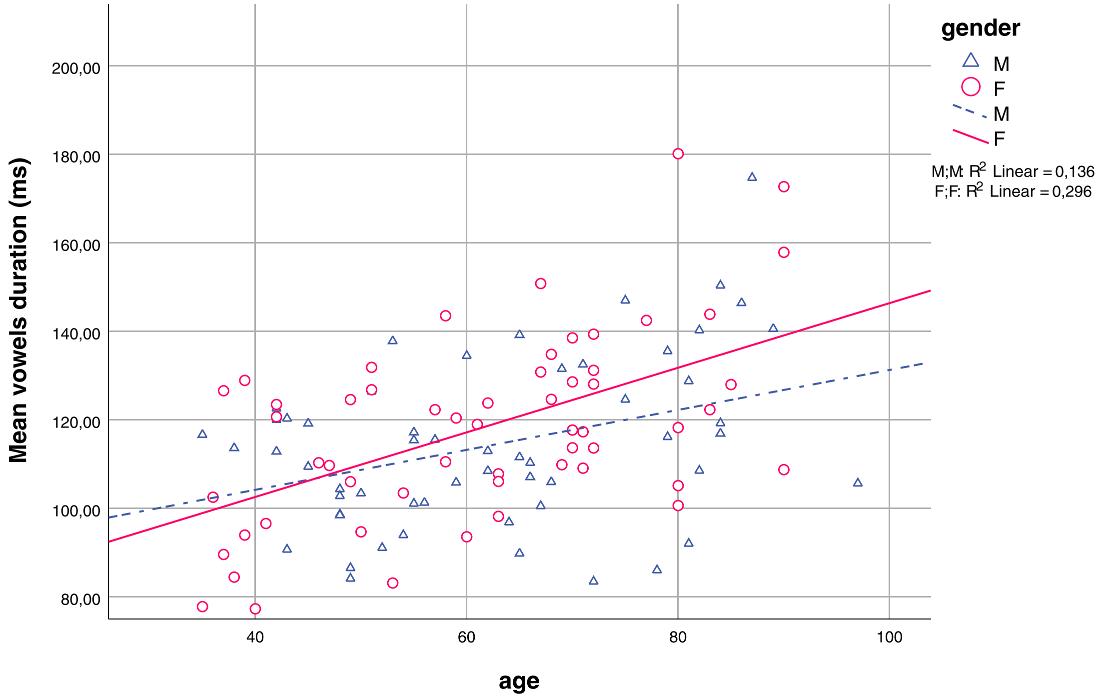

FIGURE 1. Scatterplot and regression lines for vowels duration by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

replacing the variable age for 35 and 100. f0 frequencies of all vowels tended to decrease in women (mainly in unstressed vowels) and to slightly increase in men (except the unstressed vowels), with aging. So, f0 tended to approach between genders as age increase.

Age effects in formant frequencies were vowel and gender dependent

As in previous sections, analysis of vowel formants start by showing scatterplots and regression of mean frequencies (Figures 4–6). Vowel space based on regression results by

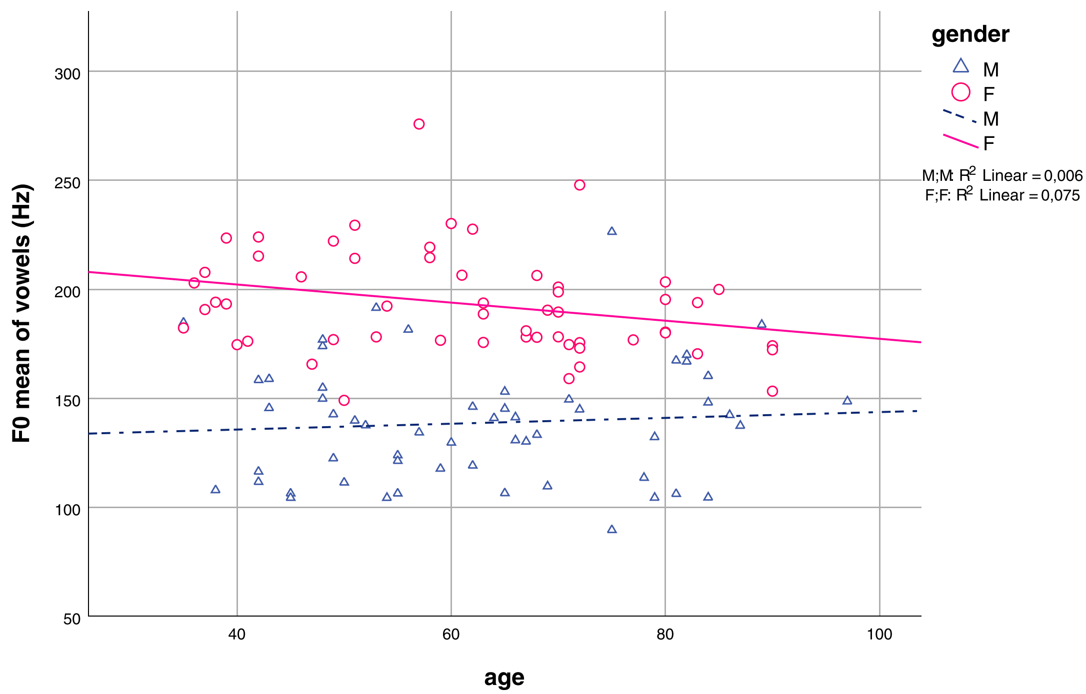

FIGURE 2. Scatterplot and regression lines for mean f0 by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

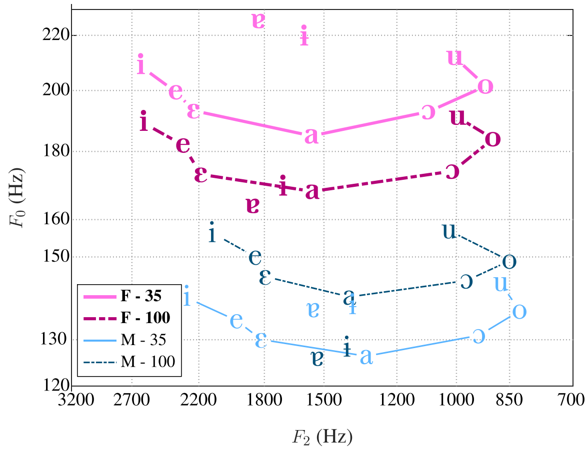

FIGURE 3. Mean value of f0 as a function of vowel and age. Top: women; bottom: men. Solid lines: 35 years; dashed lines: 100 years. This figure was drawn using equations of linear regression (of each vowel by gender) replacing the variable age by 35 and 100 (as an approximation to the age of the oldest speaker of the sample).

gender and age is presented in Figure 7. Due to the complexity of the results, the multiple linear regression coefficients are displayed in Table 2.

Figure 4 shows that mean F1 tended to decrease with age in both genders, mainly in women.

The results of multiple linear regression coefficients (Table 2) revealed significant differences between genders for all vowels (except for central vowels ([ɨ], [ɐ], and [a]) and [ɛ]), with women presenting significantly higher mean F1 (486.3 ms ± 29.7) than men (436.4 ms ± 25.9). There was a significant age effect: in males for vowels [a] (Figure 8) and [e]; and in females for vowels [ɔ] and [u].

Summing up, as illustrated in Figure 7, F1 decreased with age, especially for vowels [a] and [ɔ], but increased for vowels [e], [i], and [ɨ] in males. In females, F1 decreased with age, especially for vowels [u], [ɔ], and [a].

As shown in Figure 5, mean F2 did not reveal remarkable changes with age. The statistical analysis revealed a main effect of gender on F2 (see Table 2): women's mean F2 frequencies (1685.5 Hz ± 62.3) were significantly higher than those of men (1433.6 Hz ± 62.1). Only vowel [ɨ] did not present significant differences between genders.

A reliable effect of age was found for some vowels depending on gender. Considerable decrease in F2 was found for males in vowel [i] and an opposite tendency was observed in [u] (see Figure 9). Female [ɔ] displayed an F2 decrease with aging.

Mean F3 of the vowels (Figure 6) tended to slightly decrease with age in both genders, mainly in women.

As seen in Table 2, there was a significant effect of gender for F3, with males (2440.5 ms ± 109.3) to have lower F3 mean values than females (2830.3 ms ± 132.3). In addition, there was no significant age effect in men and women, except for female [u], that decreased sharply with age.

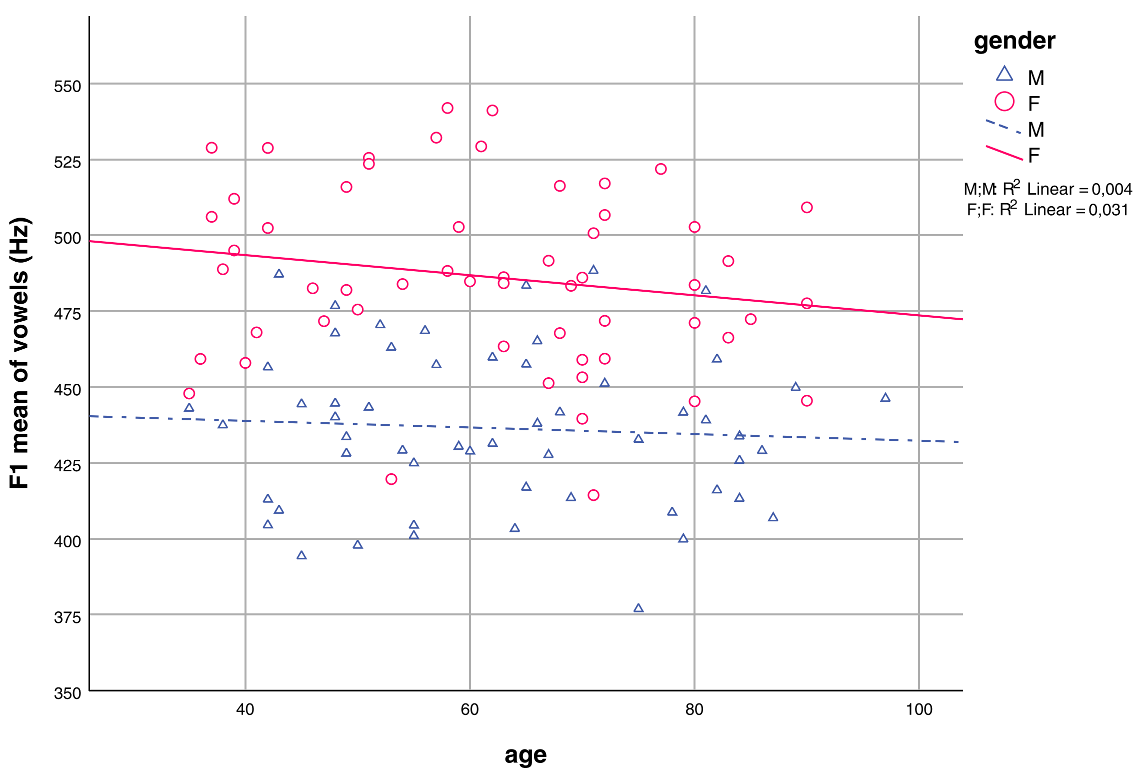

FIGURE 4. Scatterplot and regression lines for mean F1 by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

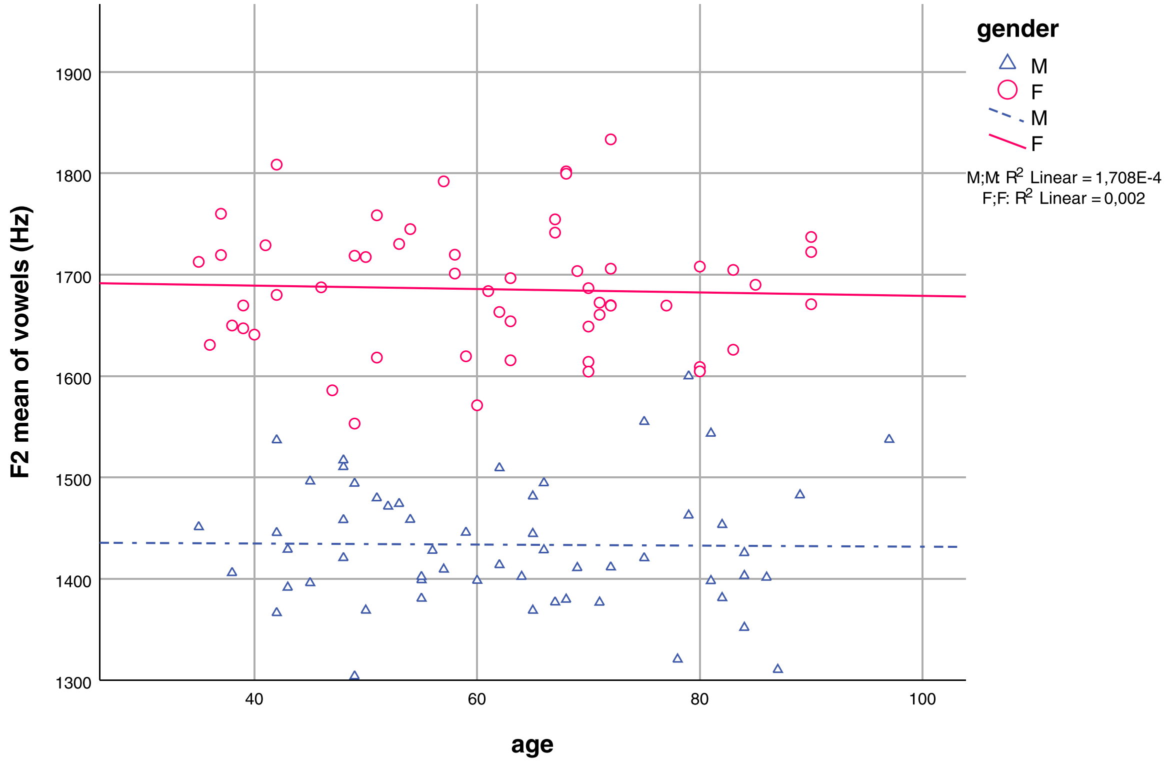

FIGURE 5. Scatterplot and regression lines for mean F2 by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

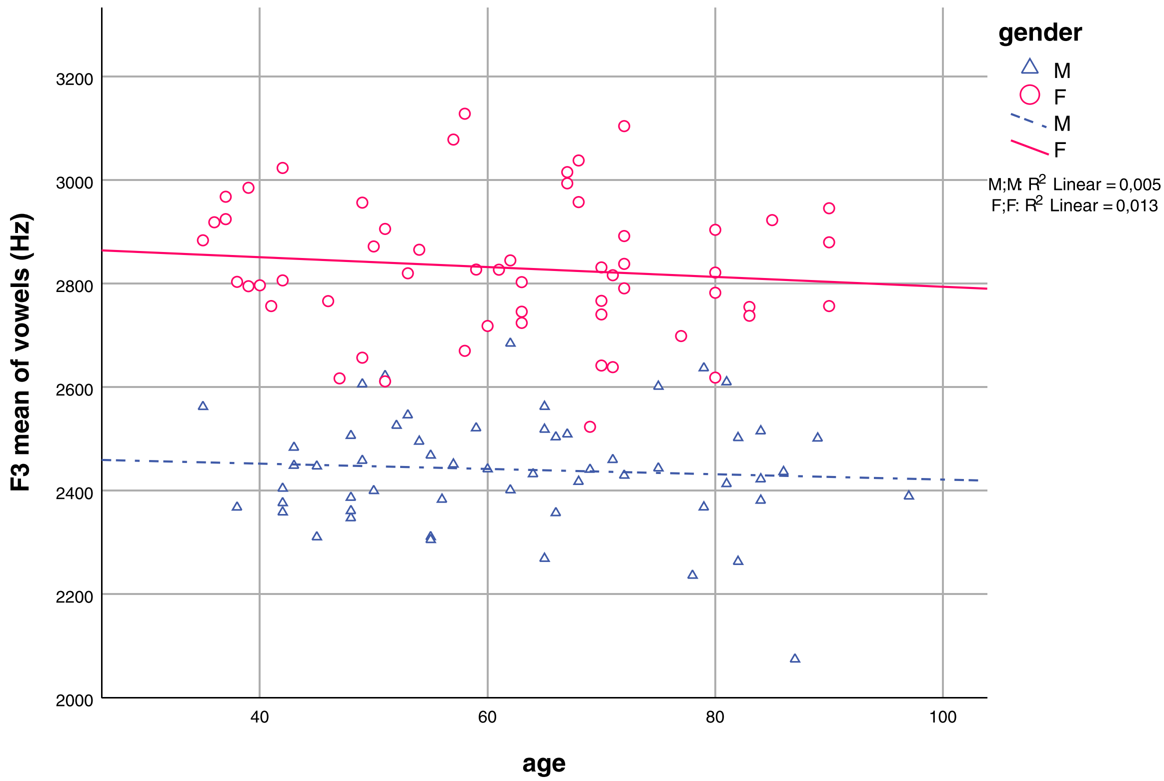

FIGURE 6. Scatterplot and regression lines for mean F3 by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

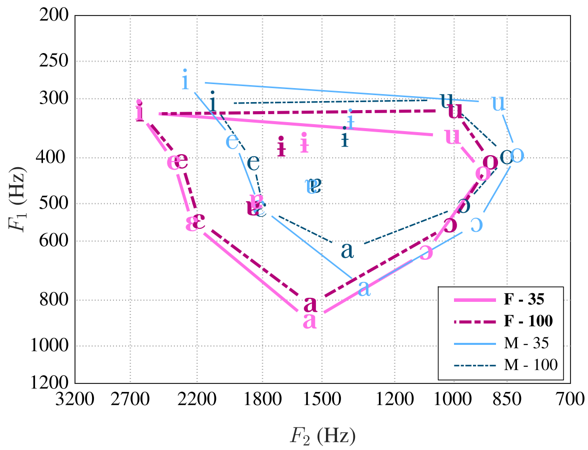

FIGURE 7. Vowel Space for men and women as a function of age. Bold lines and symbols: women; non bold lines and symbols: men. Solid lines: 35 years; dashed lines: 100 years. This figure was drawn using equations of linear regression (of each vowel by gender for F1 and F2) replacing the variable age for 35 and 100 (as an approximation to the age of the oldest speaker of the sample).

Age and gender effects on acoustic vowel space

Changes in vowel space size were computed in order to track the relationship between talker age and vowel centralization or expansion.

The scatterplot of the F1RR is presented in Figure 10. The regression lines show a decrease with age in both genders, mainly in males, whose F1RR decreased from 2.6 to 2.0 as age increased. The multiple linear regression results revealed that for F1RR only the age effect on males was significant ($B = -0.009$; $P = 0.006$; $IC95\% = [-0.015; -0.003]$). Moreover, the average F1RR of women was 2.609 (SD = 0.422) and 2.345 (SD = 0.307) for men. The female F1 space was therefore 2.609/2.345 = 1.135 times bigger than the male F1 space, although statistical model did not reveal a main effect of gender ($B = 0.220$; $P = 0.433$; $IC95\% = [-0.335; 0.775]$).

Figure 11 presents the mean F2RR and indicates a decrease with age only in males (F2RR decreased around 0.5 points between the ages 35 and 100). The effect of age and gender on F2RR was also analyzed, and as with F1RR, the statistical analysis only revealed a main effect of age in

TABLE 2.
Results of Multiple Linear Regression: the Effect of Gender and Gender*Age Interaction on F1, F2, and F3 Values by Vowel

		Intercept			Gender (Male)			Male * Age			Female * Age		
	Vowel	B	95% CI		B	95% CI		B	95% CI		B	95% CI	
F1	ɨ	371.54	329.35	413.73	−52.17	−112.77	8.42	0.46	−0.21	1.14	0.11	−0.55	0.78
	ɐ	484.63	433.43	535.82	−25.67	−99.20	47.87	−0.03	−0.85	0.79	0.25	−0.55	1.06
	a	921.76	832.36	1011.17	−99.06	−227.47	29.36	−1.96	−3.39	−0.53	−1.05	−2.45	0.36
	e	409.51	375.87	443.14	−62.75	−111.06	−14.45	0.62	0.08	1.16	−0.04	−0.57	0.49
	ɛ	554.03	509.26	598.81	−49.76	−114.07	14.56	0.08	−0.63	0.80	−0.10	−0.80	0.61
	i	318.92	286.36	351.48	−59.60	−106.37	−12.84	0.48	−0.04	1.00	0.04	−0.47	0.55
	o	442.72	408.10	477.35	−50.73	−100.46	−1.00	0.05	−0.51	0.60	−0.35	−0.90	0.20
	ɔ	674.54	618.92	730.16	−96.78	−176.66	−16.89	−0.75	−1.64	0.14	−1.21	−2.08	−0.33
	u	382.67	349.98	415.36	−74.90	−121.85	−27.95	0.06	−0.46	0.58	−0.65	−1.16	−0.14
	Mean	506.70	476.77	536.64	−63.49	−106.49	−20.49	−0.11	−0.59	0.37	−0.33	−0.80	0.14
F2	ɨ	1523.01	1390.08	1655.93	−165.49	−356.40	25.42	0.39	−1.74	2.51	1.79	−0.30	3.88
	ɐ	1815.24	1710.26	1920.22	−254.28	−405.06	−103.50	−0.30	−1.97	1.38	0.31	−1.35	1.96
	a	1563.46	1478.31	1648.62	−287.37	−409.67	−165.06	1.07	−0.29	2.43	−0.06	−1.41	1.28
	e	2392.12	2239.69	2544.55	−373.59	−592.51	−154.66	−1.69	−4.12	0.75	−0.81	−3.21	1.59
	ɛ	2255.71	2121.54	2389.87	−430.60	−623.30	−237.90	−0.35	−2.50	1.79	−0.74	−2.85	1.38
	i	2642.45	2487.84	2797.06	−264.11	−486.18	−42.05	−2.85	−5.32	−0.38	−0.37	−2.80	2.07
	o	924.77	859.08	990.46	−114.96	−209.31	−20.61	0.40	−0.65	1.45	−0.31	−1.34	0.73
	ɔ	1133.93	1071.55	1196.31	−220.95	−310.55	−131.36	0.56	−0.44	1.56	−1.19	−2.18	−0.21
	u	1012.17	882.36	1141.98	−219.64	−406.08	−33.20	2.30	0.23	4.38	−0.14	−2.18	1.91
	Mean	1695.87	1628.39	1763.36	−259.00	−355.92	−162.07	−0.05	−1.13	1.03	−0.17	−1.23	0.89
F3	ɨ	2875.24	2713.98	3036.49	−271.48	−503.08	−39.88	−1.89	−4.47	0.69	0.47	−2.07	3.01
	ɐ	2805.99	2644.83	2967.15	−366.92	−598.39	−135.46	−1.40	−3.98	1.17	−0.74	−3.28	1.80
	a	2561.37	2354.48	2768.25	−315.25	−612.39	−18.11	1.74	−1.56	5.05	1.27	−1.99	4.53
	e	2912.49	2760.88	3064.10	−424.42	−642.17	−206.67	−0.11	−2.53	2.31	−0.02	−2.41	2.36
	ɛ	2903.41	2736.52	3070.30	−502.15	−741.85	−262.44	0.82	−1.85	3.49	−1.15	−3.77	1.48
	i	3257.24	3024.54	3489.94	−313.60	−647.82	20.62	−3.05	−6.77	0.67	−2.32	−5.98	1.35
	o	2913.92	2724.79	3103.05	−484.69	−756.33	−213.05	−0.37	−3.39	2.66	−0.98	−3.96	2.00
	ɔ	2766.86	2554.54	2979.18	−447.83	−752.78	−142.88	0.62	−2.78	4.01	−0.69	−4.03	2.65
	u	3002.76	2819.95	3185.58	−619.73	−882.30	−357.16	−0.97	−3.90	1.95	−4.40	−7.28	−1.52
	Mean	2888.81	2757.77	3019.84	−416.23	−604.43	−228.03	−0.51	−2.61	1.58	−0.95	−3.01	1.11

B = Linear Coefficient

* Grey cells represent significant results (P < 0.05).

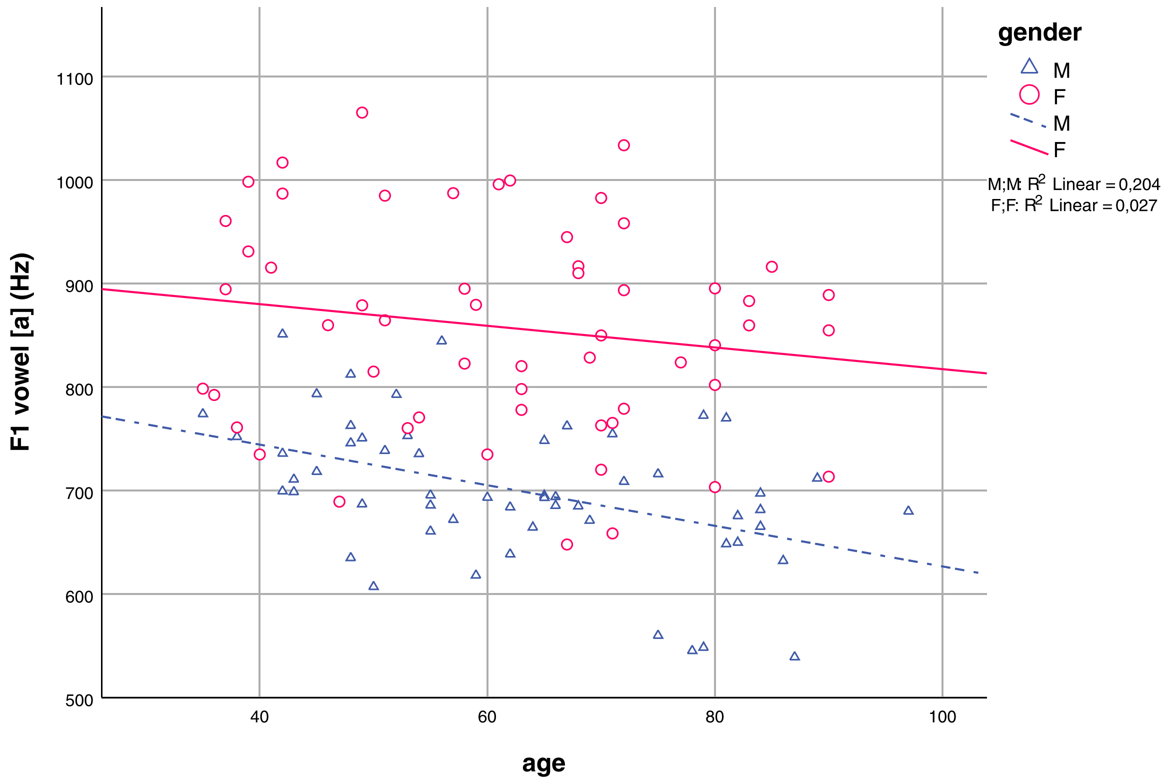

FIGURE 8. Scatterplot of F1 as function of age and gender for vowel [a] with superimposed linear regression results. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

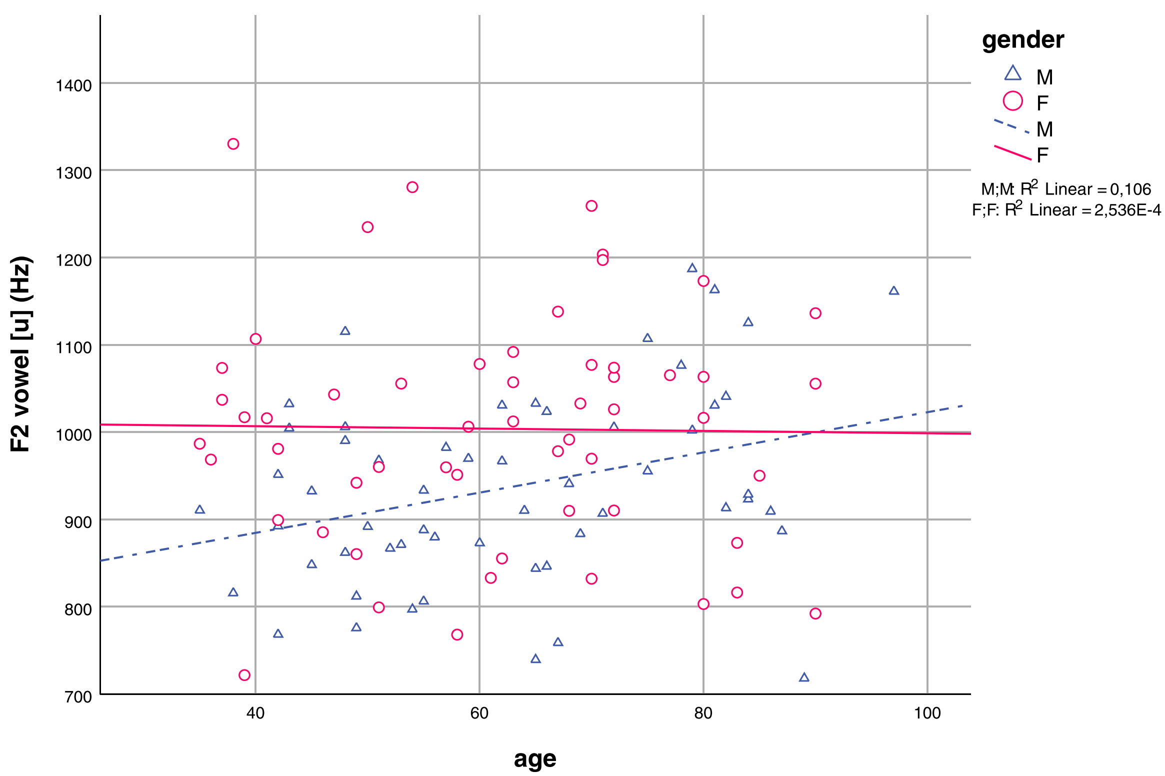

FIGURE 9. Scatterplot of F2 as function of age and gender for vowel [u] with superimposed linear regression results. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

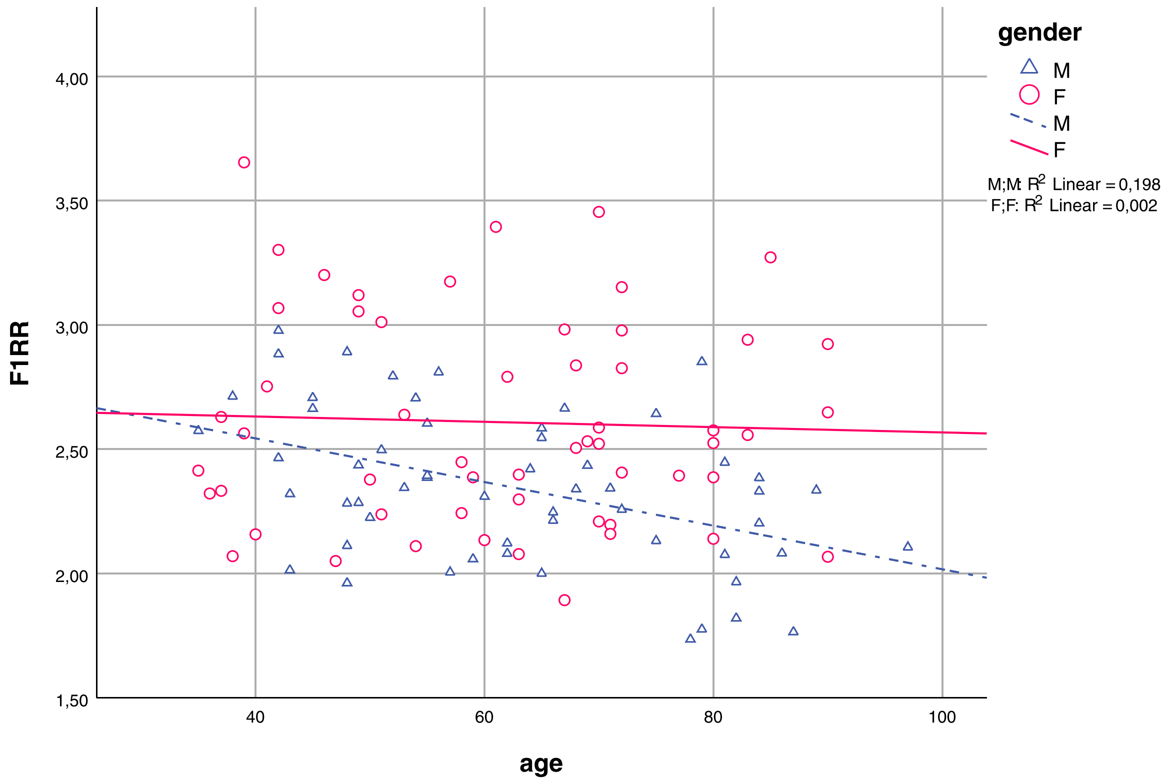

FIGURE 10. Scatterplot and regression lines for F1RR by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

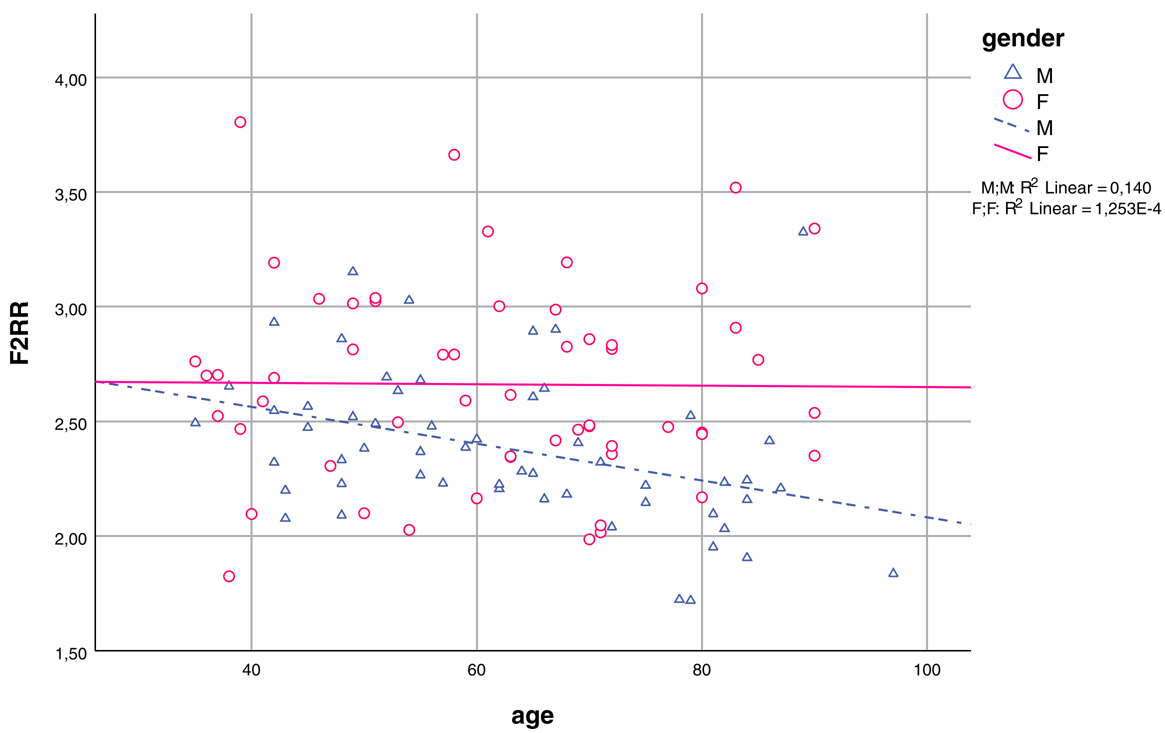

FIGURE 11. Scatterplot and regression lines for F2RR by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

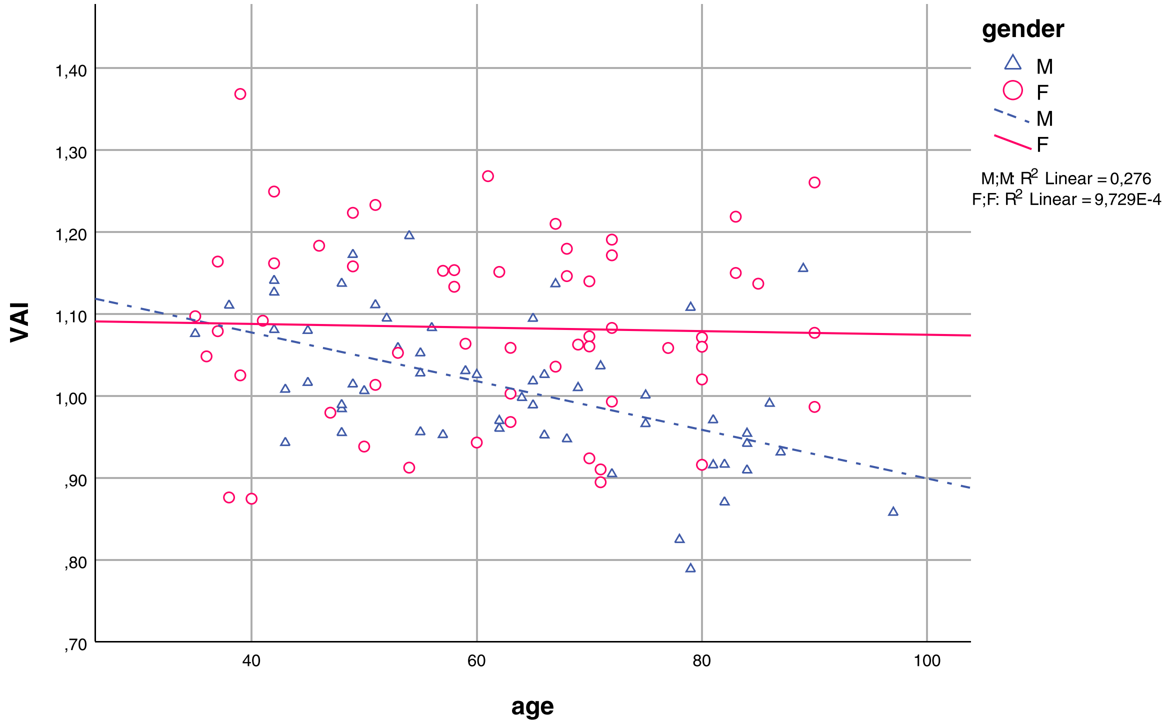

FIGURE 12. Scatterplot and regression lines for VAI by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

males ($B = -0.008; P = 0.016; IC95\% = [-0.015; -0.002]$). Similar to F1, the size of the F2 space was higher for women (2.662) than for men (2.382), ie, the female F2 space was therefore 1.118 times bigger than the male F2 space. Nonetheless, the model did not include a main effect of gender ($B = 0.204; P = 0.490; IC95\% = [-0.380; 0.787]$).

VAI (see Figure 12) and FCR were also analyzed. The regression lines of VAI show a decrease of approx. 18% between the ages of 35 and 100 for males. As expected, for males, the opposite trend was observed for FCR. For females, both parameters remained stable with age. The multiple linear regression results revealed that, for both parameters, the age effect is only significant for men (FCR: $B = 0.003; P < 0.001; IC95\% = [0.002; 0.005]$; VAI: $B = -0.003; P = 0.001; IC95\% = [-0.005; -0.001]$). As expected (they act as interspeaker normalization), the statistical model did not reveal a main effect of gender (FCR: $B = -0.127; P = 0.067; IC95\% = [-0.263; 0.009]$; VAI: $B = -0.099; P = 0.185; IC95\% = [-0.048; 0.247]$).

Additionally, Figure 7 allows to verify that males and females showed different tendencies with age, which is reflected in differences in vowel space sizes.

DISCUSSION

This study contributes to increase knowledge on EP aging speech, providing an acoustical perspective of the effects of age (as a continuous variable) in all oral vowels of the EP for several acoustic parameters. The present study extends in many ways our previous research[10] by reporting results for another formant (F3) and additional acoustic features (F1RR, F2RR, VAI and FCR). Additionally, this study aims to provide normative values for several acoustic vowel parameters of EP adult speakers. So, these normative data can be used as a database for clinical and research purposes (eg, a speech-language pathologist may wish to compare an impaired voice with a typical voice).

Similarities and differences in EP vowel acoustics presented with aging by male and female speakers were analyzed. First, as in most studies, vowels' duration increased with age. Second, a tendency for f0 to decrease in women and to slightly increase in men was observed. Thirdly, F1 and F2 space underwent a reduction in males with aging. Finally, the frequencies of F3 were essentially unchanged with age.

The results obtained are in general in line with previous research. However, some features, specially f0, did not yield as much age-related variation as reported in previous studies.[12,35,38] It should be noted these studies used different methodologies and different criteria for participant selection,[35,62,63] and in this sense the differences in results are not surprising.

The age-related changes on acoustical parameters are discussed in detail further below.

Vowels Duration

As in most studies,[8,11,12,50,51,64] vowels' duration was the acoustic parameter mostly affected by aging.[8,50,51,64] This probably occurs as a consequence of the decrease in the speech rate[6,8,65] and seems to be related to the neuromuscular slowing, altered nerve supply, respiratory changes, increased cautiousness and to the adjustment by older speakers of their tempo to maintain speech fluency.[6,8] After the vowel [ɐ], the unstressed vowel [ɨ] had the lowest duration and tended to be deleted (26,7%).[12,66] The deletion of unstressed vowels, especially of [ɨ], has been reported for many languages and also for EP.[66−71] At the same time, [ɨ] duration remains almost unchanged with age.

Fundamental Frequency

The results of our study give additional support that age related changes in f0 are gender dependent, which leads to an approximation of f0 values between genders as age increases. As in the current study, most of the literature for other languages reported a lowering of f0 with age for women, and a raising of f0 for men (not always significant).[8,35,37,38,48,72] For the EP, previous studies were consistent with the decrease of f0 in females,[12,13] whereas in males no significant age-related changes in f0 were observed.[11−13]

It has been suggested that the f0 drop in women with age results from the increase in vocal fold mass due to hormonal changes that occur during menopause.[6,7,32,36,73−75] The raise in f0 in men after middle age has been attributed to reduced vocal fold mass and stiffness of vocal fold tissues due to aging-induced atrophy of the internal thyroarytenoid.[6,37,48,74,76]

Additionally, it is important to mention that unstressed vowels behaved differently from stressed vowels with age. So, in unstressed vowels, f0 tended to decrease in both genders (although only statistically significant for females) and presented different values than expected. In other words, [ɨ] and [ɐ] f0 tended to be lower than the f0 of vowel [a] with age in both genders. This finding raises questions about the usual physiological explanation for a rise of f0 in older men,[6,37,48,74,76] that is, it remains unclear why a reduced mass and/or stiffness of vocal folds should affect only stressed vowels, whereas unstressed vowels show quite an opposite pattern.

Formant frequencies

We also observed a general lowering of F1 and F2 frequencies for women in all stressed vowels (although significant differences occurred only for F1[u], F1[ɔ] and F2[ɔ]); as men showed: (1) a decrease in F1 for low vowels (specially in [a]) and an increase in high vowels (specially in [i]); (2) an F2 decrease with age for [i], and a raising of F2 for [u], which suggests that only older men showed formant frequency evidence of vowel centralization, reported in previous researches.[8,24,25,38,49]

For EP, an opposite tendency was observed in Pellegrini et al,[12] which have shown a greater centralization of the vowel space in younger speakers (males and females aged 19−28). However, our study does not cover the same age range, for that it is difficult to draw solid conclusions.

Although the VSA, in the previous study,[10] did not show centralization for both genders, all the vowel space ratios selected for this comprehensive study (F1RR, F2RR, VAI, and FCR) indicated significant changes consistent with the centralization of the vowel space for male speakers. These results corroborate the main hypothesis that young males have a better articulation precision than older males.[6,15,20] Also, F2RR reflect restricted movements of the tongue in the anterior-posterior direction and restricted movements of the lips (rounding for [u] and retraction for [i]).[23] For example, an increase in F2 can be caused by a more anterior tongue position, but also by a decrease in lip rounding or tongue body shape.[77] The present results tend to confirm that the F1RR, F2RR, VAI, and FCR metrics are more sensitive to mild vowel articulation changes with age than VSA.

Several explanations have been advanced to account for age-related changes in vowel formant frequencies,[7,9,29,35,63] like altered dimensions of the back cavity,[29,78] changes of the shape of the oral cavity (loss of teeth and the introduction of dentures),[7,29] diachronic or intergenerational phonetic change[79] or slower tongue movements and loss of tongue strength.[6,43]

Additionally, as in Schötz[8] and Eichhorn et al,[35] the frequencies of F3 were essentially unchanged with age. This result does not support the idea of vocal tract lengthening in older age reported in previous studies.[9,29,43−46] So, the lack of an aging effect on the F3 indicates that any changes found for F1 and F2 are related to specific articulatory effects.[35] And also, this claim could be corroborated by the findings about males' patterns of f0 change in stressed vs. unstressed vowels.

Study limitations and future work

Given the methodological differences across previous studies, variable results are not surprising. For that, it is difficult to fix a particular age or age range where changes occur in either gender.[63]

Speaker age leaves traces in all phonetic dimensions and its impact on the voice is influenced by numerous factors, such as physiological condition, occupations and lifestyle habits,[5,8] which were not handled in this study. Also the type of speech samples used could affect the results. In more conversational contexts, speakers tend to show decreases in average vowel duration coupled with a higher degree of vowel centralization.[47] It is possible that, in order to see differences in vowel centralization with age, a task which demands greater movement of speakers' vocal tracts might be required.[47] And finally, vowel duration was not controlled, which renders comparisons across studies to be problematic in several ways.

An open and interesting question remains: whether the changes that we have observed in our data are the result of passive physiological changes to the vocal tract, or whether speech production is actively modified with increasing age, in order to compensate perceptually for the influences of the age-related decline on vowel quality. For that, the relation between the vowel acoustic and the articulatory changes with aging will be addressed in future work using instrumental techniques, such as ultrasonography.

Additionally, dynamic measurements of vowels' formant would be highly desirable, to provide a more complete view of vowel characteristics, and to avoid a necessarily arbitrary choice of selecting a specific time point where the measurements are taken.

Given that in cross-sectional studies speakers include various factors other than age alone, that could affect the results. In future, we plan to develop a longitudinal research study that traces the acoustic features of the same speaker over a long period of time.

The acoustic changes resulting from the natural process of aging are an important basis to understand speech and voice disorders associated with health conditions that affect older individuals (eg, hearing loss, dentofacial alterations, neurodegenerative diseases, stroke, cancer, or psychological distress).[35] Wherefore, it is very important that voice clinicians are aware of such effects and take these into account in their intervention. Furthermore, the correlates of speaker age reported in this study may further be helpful for the development of methods for the automatic detection of speaker age, as well as for the synthesis of speaker age. Thereby, better age recognizers or classifiers may be achieved, as well as better and more natural-sounding synthesis of speaker age.[8]

CONCLUSION

The results of this study provide a base of information to establish vowel acoustics normal patterns of aging among Portuguese adults. So, this study adds to the growing body of data on the effects of age on the acoustic properties of speech, providing information on vowel acoustics from adults who speak a language different from English. In that sense, it might help to better understand cross-linguistic similarities and language-particular features of vowel aging.

Summing up, the statistical analyses have shown which vowels are more affected by aging: (1) the unstressed oral vowels f0, mainly for females; (2) formants of vowels [u] and [ɔ] for females; (3) vowels [i], [u], [a], and [e] males' formants.

Acknowledgments

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APPENDIX A. VOWEL DURATION

TABLE A1.
Mean and Standard Deviation (SD) of Vowel Duration Values (ms)

	Male				Female			
	[35–49] Mean (SD)	[50–64] Mean (SD)	[65–79] Mean (SD)	≥80 Mean (SD)	[35–49] Mean (SD)	[50–64] Mean (SD)	[65–79] Mean (SD)	≥80 Mean (SD)
ɨ	71.5 (14.3)	75.2 (13.3)	77.7 (15.4)	75.5 (15.8)	71.2 (9.8)	74.1 (12.8)	76.6 (17.2)	80.3 (14.6)
ɐ	57.6 (10.0)	59.1 (7.5)	60.9 (10.6)	67.1 (11.0)	56.5 (9.3)	58.8 (5.6)	61.8 (10.6)	64.3 (12.1)
a	135.0 (17.9)	136.4 (18.7)	138.6 (23.6)	151.2 (30.8)	132.2 (27.1)	143.2 (23.9)	156.3 (20.2)	159.4 (33.3)
e	132.4 (17.3)	138.0 (16.9)	141.4 (23.1)	154.5 (29.1)	130.3 (23.1)	140.9 (20.1)	153.5 (14.3)	167.2 (38.2)
ɛ	114.9 (15.9)	116.2 (16.8)	121.5 (25.6)	143.1 (31.0)	113.0 (20.2)	123.4 (18.2)	141.3 (18.2)	144.4 (32.4)
i	107.6 (16.5)	111.9 (21.1)	118.1 (29.1)	140.5 (30.8)	101.7 (18.9)	112.5 (20.1)	131.8 (18.0)	143.8 (32.2)
o	115.7 (10.4)	120.8 (18.2)	128.1 (25.0)	146.4 (29.9)	111.5 (20.1)	118.8 (22.9)	136.9 (19.7)	146.5 (38.7)
ɔ	114.9 (17.6)	119.3 (16.6)	127.7 (27.0)	145.6 (32.0)	119.7 (25.6)	127.1 (24.6)	146.9 (15.6)	152.2 (37.4)
u	110.3 (23.1)	119.9 (18.4)	118.5 (23.8)	140.5 (36.4)	107.2 (27.1)	112.1 (25.5)	136.9 (17.9)	145.6 (44.8)
Mean	106.7 (12.8)	110.8 (14.0)	114.7 (19.9)	129.4 (23.8)	104.8 (17.8)	112.3 (16.4)	126.9 (12.5)	133.7 (28.5)

APPENDIX B. FUNDAMENTAL FREQUENCY

TABLE B1.
Mean and standard deviation of vowel f0 values.

	Male				Female			
	[35-49] Mean (SD)	[50-64] Mean (SD)	[65-79] Mean (SD)	≥80 Mean (SD)	[35-49] Mean (SD)	[50-64] Mean (SD)	[65-79] Mean (SD)	≥80 Mean (SD)
ɨ	138.8 (22.3)	133.3 (27.9)	128.4 (27.5)	134.6 (19.4)	203.9 (31.3)	213.0 (45.2)	195.7 (32.5)	173.2 (17.9)
ɐ	140.0 (25.6)	130.6 (23.4)	124.8 (26.2)	137.1 (19.8)	210.8 (29.7)	213.5 (41.4)	196.6 (33.0)	172.1 (14.8)
a	133.1 (28.5)	126.6 (23.3)	127.5 (33.2)	143.0 (23.2)	180.8 (15.7)	188.8 (25.6)	170.0 (17.5)	174.0 (19.3)
e	141.4 (29.3)	135.2 (27.9)	136.1 (36.7)	153.4 (28.3)	195.1 (21.6)	203.9 (30.9)	183.2 (20.3)	186.0 (18.6)
ε	138.1 (31.6)	130.2 (24.2)	132.7 (34.3)	148.4 (25.8)	188.7 (19.6)	193.3 (28.3)	176.7 (22.1)	179.4 (16.3)
i	146.7 (31.4)	138.6 (26.1)	143.5 (36.3)	158.9 (32.1)	202.7 (20.3)	212.8 (33.1)	192.6 (22.7)	193.2 (18.7)
o	143.7 (30.6)	135.5 (25.8)	136.9 (33.0)	153.9 (28.4)	196.4 (20.2)	206.9 (33.2)	186.8 (24.3)	187.7 (18.0)
ɔ	138.1 (29.3)	131.4 (25.1)	130.5 (34.6)	148.4 (24.9)	188.4 (17.7)	196.1 (29.4)	175.7 (20.9)	180.2 (18.2)
u	149.3 (31.4)	142.2 (28.6)	145.8 (34.7)	160.6 (30.9)	206.2 (20.1)	214.9 (38.5)	194.8 (25.0)	195.0 (18.6)
Mean	141.0 (27.6)	133.7 (25.0)	134.0 (31.7)	148.7 (25.3)	197.0 (19.3)	204.8 (30.7)	185.8 (20.9)	182.3 (15.7)

APPENDIX C. FORMANT FREQUENCIES

TABLE C1.
Mean and standard deviation of vowel F1, F2 and F3 values.

		Male				Female			
		[35-49] Mean (SD)	[50-64] Mean (SD)	[65-79] Mean (SD)	≥80 Mean (SD)	[35-49] Mean (SD)	[50-64] Mean (SD)	[65-79] Mean (SD)	≥80 Mean (SD)
F1	ɨ	336.5 (32.2)	347.8 (25.9)	356.1 (35.5)	354.5 (44.6)	375.8 (44.8)	381.5 (45.0)	380.5 (52.0)	374.2 (27.7)
	ɐ	458.4 (37.9)	455.4 (34.7)	459.0 (38.3)	455.9 (41.5)	481.2 (39.2)	523.7 (74.9)	499.0 (54.2)	495.4 (37.5)
	a	741.7 (54.0)	698.8 (64.5)	682.5 (74.7)	668.1 (56.7)	885.4 (111.7)	860.2 (92.8)	842.1 (114.4)	835.6 (74.3)
	e	369.3 (34.0)	385.1 (28.3)	396.4 (36.4)	394.3 (30.8)	406.7 (24.5)	420.0 (33.3)	395.3 (27.5)	408.0 (31.2)
	ɛ	507.0 (39.3)	503.1 (37.2)	511.2 (50.5)	518.5 (21.9)	544.2 (37.3)	568.4 (52.3)	531.9 (40.0)	549.4 (36.4)
	i	288.0 (34.3)	280.3 (23.5)	286.6 (24.4)	308.6 (24.9)	312.8 (36.4)	331.3 (29.7)	323.3 (26.7)	316.7 (38.7)
	o	387.8 (33.9)	401.8 (29.1)	398.5 (34.4)	390.9 (34.9)	427.6 (28.8)	431.0 (35.0)	411.1 (31.3)	413.3 (28.6)
	ɔ	544.8 (41.3)	527.4 (38.4)	529.2 (51.4)	517.7 (33.7)	625.9 (63.1)	613.3 (68.6)	586.7 (48.6)	563.5 (60.2)
	u	314.8 (27.2)	308.4 (22.4)	306.2 (26.1)	319.2 (21.0)	348.6 (35.1)	359.9 (38.5)	327.4 (28.0)	332.5 (38.6)
	Mean	438.7 (26.5)	434.2 (25.4)	436.2 (30.6)	436.4 (22.0)	489.8 (25.8)	498.8 (33.8)	477.5 (30.8)	476.5 (21.4)
F2	ɨ	1378.5 (131.8)	1366.1 (99.4)	1413.4 (115.5)	1363.6 (185.3)	1597.0 (127.1)	1607.6 (101.7)	1667.0 (131.2)	1671.9 (87.9)
	ɐ	1547.9 (114.2)	1534.5 (51.2)	1561.7 (96.7)	1519.8 (82.8)	1803.6 (84.1)	1835.1 (115.1)	1893.2 (89.5)	1784.3 (105.9)
	a	1331.5 (69.4)	1324.9 (60.4)	1358.1 (88.1)	1363.0 (104.6)	1543.3 (77.0)	1580.5 (87.4)	1548.9 (65.7)	1569.5 (90.1)
	e	1959.8 (99.7)	1912.2 (109.2)	1894.1 (155.9)	1875.3 (114.4)	2342.3 (162.5)	2343.8 (169.5)	2384.6 (161.8)	2272.7 (125.9)
	ɛ	1813.6 (110.4)	1809.1 (90.3)	1787.6 (126.7)	1801.5 (97.0)	2222.2 (146.4)	2200.8 (144.0)	2226.4 (143.6)	2181.4 (135.0)
	i	2256.7 (120.1)	2217.3 (113.3)	2173.2 (161.2)	2134.7 (121.4)	2623.1 (170.8)	2618.6 (147.4)	2621.5 (183.3)	2614.9 (115.9)
	o	825.8 (51.7)	849.3 (60.5)	825.8 (48.3)	840.4 (72.3)	908.2 (61.6)	917.5 (66.3)	887.6 (53.7)	913.5 (82.2)
	ɔ	945.4 (55.9)	941.8 (37.0)	951.2 (62.4)	955.4 (67.8)	1084.5 (72.6)	1071.0 (46.0)	1045.1 (56.0)	1033.1 (74.6)
	u	914.4 (102.3)	908.9 (65.7)	953.9 (126.5)	981.7 (136.4)	991.2 (134.6)	996.2 (147.2)	1045.4 (115.6)	967.9 (141.4)
	Mean	1441.5 (63.6)	1429.3 (41.3)	1435.4 (74.1)	1426.2 (72.7)	1679.5 (65.7)	1685.7 (61.6)	1702.2 (66.9)	1667.7 (52.1)
F3	ɨ	2477.5 (142.4)	2532.8 (152.7)	2514.4 (146.7)	2392.5 (170.4)	2880.1 (111.9)	2930.8 (119.5)	2899.2 (202.8)	2907.3 (116.4)
	ɐ	2360.1 (185.0)	2355.2 (130.7)	2377.8 (120.6)	2297.3 (160.4)	2776.4 (125.7)	2733.1 (173.4)	2772.6 (183.2)	2759.1 (89.7)
	a	2298.1 (127.4)	2358.0 (189.4)	2402.8 (139.6)	2365.0 (215.2)	2625.5 (180.8)	2591.3 (209.1)	2668.9 (210.5)	2685.5 (279.1)
	e	2492.4 (110.0)	2480.1 (149.6)	2476.0 (128.3)	2474.4 (162.0)	2899.0 (97.7)	2912.9 (173.1)	2932.7 (162.5)	2891.2 (150.7)
	ɛ	2424.8 (178.2)	2481.7 (187.4)	2431.3 (91.2)	2479.9 (205.6)	2855.9 (105.4)	2826.5 (129.7)	2822.2 (176.4)	2825.3 (164.5)
	i	2777.7 (170.7)	2816.2 (223.1)	2699.2 (219.0)	2703.4 (222.0)	3175.7 (243.3)	3086.6 (194.6)	3130.9 (255.0)	3039.2 (205.9)
	o	2386.2 (125.5)	2429.5 (134.8)	2425.4 (123.8)	2376.2 (137.2)	2870.7 (209.1)	2860.1 (223.3)	2818.8 (238.0)	2873.5 (169.8)
	ɔ	2311.2 (156.0)	2389.4 (181.7)	2395.2 (136.3)	2326.5 (202.6)	2740.3 (192.4)	2709.7 (237.0)	2727.8 (259.7)	2716.6 (195.6)
	u	2325.7 (128.1)	2348.7 (144.5)	2328.6 (152.5)	2272.0 (153.1)	2768.9 (208.9)	2811.1 (215.4)	2698.7 (184.8)	2611.3 (158.6)
	Mean	2428.2 (84.0)	2465.7 (104.7)	2450.1 (112.4)	2409.7 (142.9)	2843.6 (120.0)	2829.1 (137.5)	2830.2 (162.6)	2812.1 (101.8)

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