Age and gender effects in European Portuguese spontaneous speech

L. Albuquerque[1,2,3,4], A. R. S. Valente[1,3], A. Teixeira[1,3], C. Oliveira[1,5], D. Figueiredo[2,5]

[1] Institute of Electronics and Informatics Engineering of Aveiro, University of Aveiro, Aveiro, Portugal
[2] Center of Health technology and Services Research, University of Aveiro, Aveiro, Portugal
[3] Department of Electronics Telecommunications and Informatics, University of Aveiro, Aveiro, Portugal
[4] Department of Education and Psychology, University of Aveiro, Aveiro, Portugal
[5] School of Health Science, University of Aveiro, Aveiro, Portugal
lucianapereira@ua.pt ORCID: https://orcid.org/0000-0003-1654-3272
rita.valente@ua.pt ORCID: https://orcid.org/0000-0002-0511-554X
ajst@ua.pt ORCID: https://orcid.org/0000-0002-8120-0148
coliveira@ua.pt ORCID: https://orcid.org/0000-0002-3389-3082
daniela.figueiredo@ua.pt ORCID: https://orcid.org/0000-0002-3160-7871

Citation / Cómo citar este artículo: L. Albuquerque, A. R. S. Valente, A. Teixeira, C. Oliveira, D. Figueiredo (2021), Age and gender effects in European Portuguese spontaneous speech. *Loquens*, *8*(1-2), e077. https://doi.org/10.3989/loquens.2021.e077.

ABSTRACT: Aging is part of the normal evolution of human beings. However, the knowledge about speech in the older ages is still dispersed and incomplete. Considering conflicting findings reported in prior research, this study aims to contribute to increase our knowledge about age effects on the spontaneous speech of Portuguese adults. In order to analyze the effects of age on rhythmic, intonation and voice quality domains, several parameters were extracted from spontaneous speech produced by 112 adults, aged between 35 and 97. Data were obtained through a picture description task. The results showed that the most consistent age-related effects are an increase in speech pauses, mainly in men, and a Harmonics-to-Noise Ratio (HNR) decrease in women. Speaking fundamental frequency (f_0) tends to decrease in women and to slightly increase in men with age. These findings for Portuguese are in line with previous research suggesting that suprasegmental characteristics of speech change with age, with some gender differences.

Keywords: aging, spontaneous speech, rhythm, speaking fundamental frequency

RESUMEN: *Efectos de la edad y del sexo en el habla espontánea en portugués europeo.-* El envejecimiento es parte de la evolución normal del ser humano. Sin embargo, el conocimiento sobre el habla en las edades más avanzadas todavía es disperso e incompleto. Teniendo en cuenta los hallazgos contradictorios referidos en investigaciones anteriores, este estudio tiene como objetivo contribuir a aumentar el conocimiento sobre los efectos de la edad en el habla espontánea de los adultos portugueses. Para analizar los efectos de la edad en los dominios del ritmo, entonación y calidad vocal, se extrajeron varios parámetros del habla espontánea producida por 112 adultos, con edades entre 35 y 97 años. Los datos se obtuvieron mediante una tarea de descripción de imágenes. Los resultados demostraron que los efectos relacionados con la edad más constantes fueron un aumento en las pausas del habla, principalmente en los hombres, y una disminución del ratio armónico-ruido en las mujeres. La frecuencia fundamental del habla (f_0) tiende a disminuir en las mujeres y a aumentar ligeramente en los hombres con la edad. Estos hallazgos para el portugués están de acuerdo con investigaciones previas que sugieren que las características suprasegmentales del habla cambian con la edad, con algunas diferencias de género.

Palabras clave: envejecimiento, habla espontánea, ritmo, frecuencia fundamental

1. INTRODUCTION

The older population is quickly increasing worldwide. Demographic aging, due primarily to lower fertility, also reflects a human success history of increased longevity (He, Goodkind, & Kowal, 2016; Kart & Kinney, 2001). According to the World Health Organization, the number of people aged over 65 is rising, and by 2050, 1 in 6 people in the world will be over the age of 65, up from 1 in 11 in 2019 (United Nations Department of Economic and Social Affairs Population Division, 2019). Portugal is also one of the developed countries with the highest rate of older population (between 1970 and 2019, the percentage of people aged 65 and over increased from 9.7% to 22.4%) (Statistics Portugal, 2015, 2019; United Nations Department of Economic and Social Affairs Population Division, 2019).

Aging, as a normal and inevitable process, involves physiological, cognitive, psychological, and social changes (Hermes, Mertens, & Mücke, 2018; Makiyama & Hirano, 2017). The physiological aging affects all speech organs. In this sense, age-related changes in speech organs as well as in neuro-muscular control determine considerable variation in speech production and speech planning across the life span (Hermes et al., 2018; Pellegrino, He, & Dellwo, 2018). These changes alter considerably the way individuals speak over time both segmentally and suprasegmentally (Pellegrino et al., 2018). Although most studies have focused on the production of segments, such as vowels, the suprasegmental characteristics of speech are also particularly vulnerable to age. However, the effect of aging on suprasegmental characteristics of speech, i.e., in speech rhythm and intonation has been investigated in far less detail.

Concerning European Portuguese (EP), there are only a few studies regarding age-related speech variations, mainly, at the segmental level (Albuquerque, Oliveira, Teixeira, Sa-Couto, & Figueiredo, 2019; Albuquerque et al., 2014; Guimarães & Abberton, 2005; Pellegrini et al., 2013). Still, vowel production in reading tasks failed to provide a clear picture of the age effects in spontaneous speech and has some limitations. To the best of our knowledge, there is almost no data on the acoustic correlates of aging on EP spontaneous speech (Guimarães & Abberton, 2005).

For this reason, the aim of this study is to analyze the effects of aging on speech rhythm (duration measures, speech and articulation rate), intonation (speaking fundamental frequency (f_0)) and voice quality (Harmonics-to-Noise Ratio (HNR)) measured in spontaneous speech. This study considers age as a continuous variable in the analysis avoiding the effects of arbitrary age groups division (as in Albuquerque, Oliveira, Teixeira, Sa-Couto, & Figueiredo (2020)).

Since there is a paucity of literature on EP speech acoustics and the available data were collected from a small number of speakers (Albuquerque et al., 2014; Escudero, Boersma, Rauber, & Bion, 2009; Martins, 1973; Oliveira, Cunha, Silva, Teixeira, & Sa-Couto, 2012), this study also provides valuable insights to understand the aging effects on natural spoken language production.

Knowledge of how speech changes with age is essential for the development of automatic speech recognition (ASR) systems suitable for older voices (i.e., personalized reading aids and voice prostheses) (Vipperla, Renals, & Frankel, 2010), for clinical assessment and treatment of different speech disorders that are often age-related, and to provide information for other fields of knowledge (i.e., phonetics, speech science, forensic linguistics and biometric recognition).

2. RELATED WORK

Many studies have addressed the effects of aging on the acoustic properties of speech (Eichhorn, Kent, Austin, & Vorperian, 2018; Linville, 2001; Schötz, 2006). Most of them have focused on segmental features and have shown an increase of segment duration (Albuquerque et al., 2020; Linville, 2001; Schötz, 2006). Despite spontaneous speech characteristics having been investigated in far less detail, acoustic studies have also revealed age-induced effects at suprasegmental level (i.e., intonation and rhythm), but they have focused mainly on reading speech.

A commonly reported effect of aging on speech is that pause duration as well as the use of speech pauses tend to increase (Hartman & Danhauer, 1976; Steffens, 2011). The reduced speech (or articulation) rate with age has also been reported, regardless of the speaker's language (Bourbon & Hermes, 2020; Hazan et al., 2018; Hermes, Bourbon, & Cecile, 2020; Linville, 2001; Pellegrini et al., 2013; Pellegrino, 2019; Schötz, 2006; Smith, Wasowicz, & Preston, 1987; Volín, Tykalová, & Bořil, 2017). However, Jacewicz et al. (2009, 2010), Brückl & Sendlmeier (2003), and Gerstenberg et al. (2018) did not find a decline in speech or articulation rate with aging. In general, the use of more speech pauses, and the associated slowing of speech rate can directly be traced to an aggravation of the lung-function (Schötz, 2006; Steffens, 2011).

Speaking f_0 has been found to be sensitive to the aging effect, tending to decrease in older females (Goy, Fernandes, Pichora-Fuller, & van Lieshout, 2013; Hazan et al., 2018; Morgan & Rastatter, 1986; Winkler, 2004). For men, most studies have reported that f_0 decreases from young adulthood into middle age and then rises again into older ages (about 35 Hz) (Linville, 2001; Pegoraro Krook, 1988; Rojas, Kefalianos, & Vogel, 2020). Other studies have indicated that speaking f_0 decreases (Vipperla et al., 2010), while others have suggested a speaking f_0 increase in older age (Dunashova, 2021; Ramig & Ringel, 1983; Winkler, 2004).

Another parameter that impacts how voices sound is the Harmonics-to-Noise Ratio (HNR), which quantifies the amount of noise in the voicing signal (Dehqan, Scherer, Dashti, Ansari-Moghaddam, & Fanaie, 2013; Ferrand, 2002; Mautner, 2011; Stathopoulos, Huber, & Sussman, 2011; Xue & Deliyski, 2001) Generally, HNR, in sustained vowels, has been reported to decrease with age, mainly in females (Dehqan et al., 2013; Ferrand,

2002; Xue & Deliyski, 2001). Nonetheless, in other studies almost no age-related variation was found for women (Ambreen, Bashir, Tarar, & Kausar, 2019; Goy et al., 2013; Schötz, 2006) or men (Ambreen et al., 2019; Goy et al., 2013). Furthermore, in Schötz (2006), a slight decrease followed by an increase after age 50 was observed in male HNR.

For EP, acoustic studies about age-related changes on spontaneous speech are scarce. Previous studies with different speech corpora (e.g., reading or conversation), indicated a slight or significant age-related f_0 decrease in women, and a non-agreement in men (Albuquerque et al., 2019, 2014; Guimarães & Abberton, 2005; Pellegrini et al., 2013). In reading tasks, Pellegrini et al. (2013) refer that speech rate decreases and the percent pause ratio increases with age for both genders. Given that previous research used different corpora and analysis procedures, it is hard at this time to draw solid conclusions on the effects of age and gender on EP spontaneous speech.

3. 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 signed a written informed consent form.

3.1. Participants

A total of 112 native Portuguese speakers, from the central region of Portugal, aged between 35 and 97, participated in this study. They covered 4 age groups: [35-49] (15 men, 15 women), [50-64] (15 men, 15 women), [65-79] (15 men, 16 women), and ≥80 (11 men, 10 women).

Each participant completed a written questionnaire and reported: no history of speech-language impairment; no severe hearing problems; and no history of neurological disorders or head/ neck cancer. Also, the participant inclusion criteria consisted of individuals free of upper respiratory tract infection for 3 weeks prior to the experiment. Participants were excluded if they: 1) were current smokers or had smoked within the previous 5 years; 2) self-reported poor general health; 3) wore hearing aids, 4) had received speech and language therapy, and 5) reported that their voice was different than usual on the day of testing (i.e., having a cold or allergy symptoms). Participants who exhibited any observable sign of speech, voice or severe hearing problems, as assessed by a speech pathologist on the moment of recording, and those who were unable to follow directions were excluded.

3.2. Corpus and recording protocol

Spontaneous speech samples were collected from the participants using the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983) picture description task, with the standardized picture "Cookie Theft" stimulus. Participants were instructed to describe the picture at comfortable pitch and loudness level, after familiarizing themselves with the image, in order to obtain induced spontaneous speech (Morgan & Rastatter, 1986; Pakhomov et al., 2011). The instruction given to participants was as follows: "Tell me everything you see in this picture.".

Recordings took place in quiet rooms using an AKG condenser microphone and USB external soundcard (PreSonus), with a sampling rate of 44100 Hz. The image was presented on the computer screen with software system SpeechRecorder (Draxler & Jänsch, 2017). 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.

3.3. Suprasegmental annotation

The recorded data was segmented through automatic Praat scripts. The speech and pauses were labeled, and in the speech intervals, the vowel onsets were also detected.

The Praat Script Syllable Nuclei v2 (modified by Hugo Quené, Ingrid Persoon, & Nivja de Jong and is available in: https://sites.google.com/site/speechrate/Home/praat-script-syllable-nuclei-v2) (de Jong & Wempe, 2009) was used to automatically detect silent pauses of over 250 ms length (Cannizzaro, Harel, Reilly, Chappell, & Snyder, 2004) and create textgrid files.

The automated alignments of silent pauses were manually checked by two trained analyzers, who verified the accuracy of pause and speech intervals, and also labeled intervals with speaker or environmental noise. The intervals were labeled as: pause (breathing sound was considered as silent pause), speech, verbal non lexical (i.e., filled pauses), noise (i.e., noise that occurs during the speaker's pauses), vocal non lexical (i.e., laughter, coughing or other human noises), and speech with noise (i.e., speech intervals with environmental noise that could affect the acoustic measurements) (Pellegrino, 2019; Schuller et al., 2013).

Vocal non lexical phenomena were considered as pause time, while verbal non lexical phenomena were not included in the present analysis (Pellegrino, 2019; Tuomainen, Hazan, & Taschenberger, 2019). Speech intervals with noise were not counted for further analysis, and also the beginning and ending of all recordings were not pondered in the analysis due to sentence initial and final acoustic variability (a total of 7% of the speech intervals were excluded).

Regarding the syllables spoken, an adapted Praat script of the BeatExtractor (Barbosa, 2006, 2010) was used to detect vowel onset using a beat wave (a normalized and band-specific amplitude). The cut-off frequency was defined automatically. The thresholds were 0.1 and 0.06; the filter was defined as Butterworth and the technique was Amplitude. The total number of syllables were automatically obtained through the sum of all vowel onset detected within all valid speech intervals per speaker. A random check was done to verify the vowel onsets and confirm the script performance.

3.4. Acoustic measurements

Acoustic parameters (f_0 and HNR) were automatically extracted from the valid speech intervals, using the Praat script ProsodyDescriptor (Barbosa, 2013), with the f_0 threshold of 75 - 400 Hz for males, and 120 - 600 Hz for females. The script extracted and calculated the parameters f_0 mean (semitones (re 1 Hz)) and HNR. Each value was considered and used to obtain the average of speaking f_0 for each participant. The f_0 scale with values in semitones relative to 1 Hz was converted to Hertz.

In order to analyze the age effects in rhythm, intonation and voice quality, several parameters (Table 1) were extracted from spontaneous speech, based on the suprasegmental annotation of speech, pauses and syllables.

3.5. Statistical Analysis

The statistical analysis was conducted with the SPSS software package (SPSS 25.0). For each suprasegmental parameter, a multiple linear regression was conducted with the following explanatory variables: age (contin-

Table 1: Systematic overview of the parameters.

Parameter	Description
Total speech duration (s)	Sum of speech duration of all speech intervals
Total pause duration (s)	Sum of pause duration of all pause intervals
Total recording duration (s)	Sum of all speech and pause intervals
Percent pause time (%)	Total pause duration divided by total time (all speech and pause intervals)
Speech pause ratio	Total time talking divided by total pause time
Number of pauses	Number of pause intervals in the description task
Mean pause duration (s)	Duration average of pause length
Mean speech duration (s)	Duration average of speech length
Pause variability (s)	Standard deviation (SD) of pause length
Speech variability (s)	Standard deviation (SD) of speech length
Number of syllables	Sum of all syllable onset detected within all speech intervals
Speech rate	Number of syllables divided by the total time (include pause intervals)
Articulation rate	Syllables per seconds of speech without pauses
Speaking f0 (Hz)	Average number of vibrations per second of the vocal folds in the entire speech sample
HNR (dB)	Average ratio of the aperiodic energy to the harmonic energy

Table 2: Results of multiple linear regression: the effect of gender and gender*age interaction on suprasegmental parameters. Grey cells represent significant results ($p<0.05$).

	Intercept			Gender (Male)			Male * Age			Female * Age		
	B	**95%**	**CI**	**B**	**95%**	**CI**	**B**	**95%**	**CI**	**B**	**95%**	**CI**
Total speech duration (s)	29,20	15,58	42,82	7,24	-12,32	26,81	-0,25	-0,47	-0,03	-0,12	-0,33	0,10
Total pause duration (s)	6,93	0,88	12,99	-0,14	-8,84	8,56	0,03	-0,07	0,12	0,02	-0,08	0,12
Total recording duration (s)	36,13	18,57	53,70	7,10	-18,13	32,33	-0,22	-0,50	0,06	-0,10	-0,38	0,18
Percent pause time (%)	22,81	10,41	35,22	-10,08	-27,90	7,73	0,27	0,07	0,47	0,07	-0,13	0,26
Speech pause ratio	13,15	-2,37	28,67	-8,24	-30,54	14,05	-0,03	-0,28	0,22	-0,11	-0,35	0,14
Number of pauses	9,08	3,23	14,93	3,55	-4,85	11,95	-0,06	-0,15	0,03	-0,02	-0,11	0,08
Mean pause duration (s)	0,91	0,36	1,46	-0,53	-1,32	0,26	0,01	0,00	0,02	0,00	-0,01	0,01
Mean speech duration (s)	4,08	2,13	6,02	-1,26	-4,06	1,53	-0,01	-0,04	0,02	-0,02	-0,05	0,01
Pause variability (SD)	0,31	-0,30	0,92	-0,16	-1,04	0,72	0,01	0,00	0,02	0,01	0,00	0,02
Speech variability (SD)	1,71	1,08	2,34	0,35	-0,56	1,25	-0,01	-0,02	0,00	0,00	-0,01	0,01
Number of syllables	112,14	42,38	181,89	65,89	-34,30	166,08	-1,14	-2,25	-0,02	-0,14	-1,24	0,95
Speech rate	2,40	1,46	3,34	2,03	0,68	3,39	-0,01	-0,03	0,00	0,02	0,00	0,03
Articulatory rate	3,06	2,04	4,08	1,97	0,50	3,44	0,00	-0,01	0,02	0,03	0,01	0,04
Speaking f0 (Hz)	204,29	181,36	227,22	-82,13	-115,06	-49,20	0,07	-0,29	0,44	-0,23	-0,59	0,13
HNR (dB)	17,56	15,29	19,82	-7,07	-10,32	-3,82	0,00	-0,04	0,04	-0,05	-0,09	-0,02
	B= Linear Coefficient											

uous), gender (male: reference group, female), and the interaction between age and gender. The regression co-efficients and the correspondent 95% IC were calculated. The level of significance was p<0.05 for all statistical analyses.
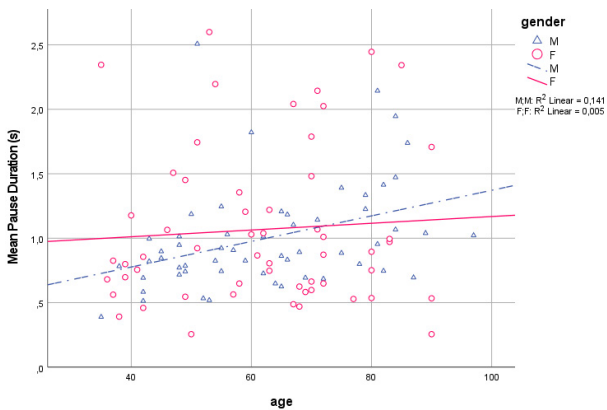
4. RESULTS

This section presents the results of the selected acoustic parameters, and their statistical analyses.

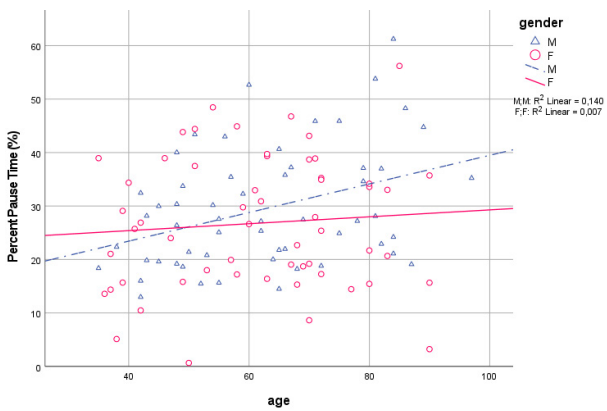The multiple linear regression coefficients are displayed in Table 2 and the results revealed significant differences between genders for the following parameters: speech rate, articulation rate, speaking f_0 and HNR. There was a significant age effect in males for total speech duration, percent pause time, mean pause duration, speech variability and number of syllables; and in females for the suprasegmental parameters: speech rate, articulation rate and HNR.

4.1. Rhythmic parameters

Concerning the mean pause duration (see Figure 1) and the percent pause time (see Figure 2), the re-

gression lines showed an increase with age, mainly in males, which means pause duration increases from approximately 0.7 s at age 35 to 1.4 s at age 100, and the percent pause time increases 20% in the same age

Figure 3: Scatterplot and regression lines for articulation rate by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.
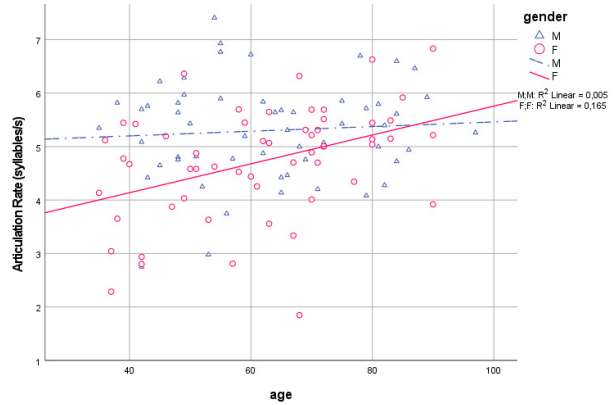

Figure 1: Scatterplot and regression lines for mean pause duration by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

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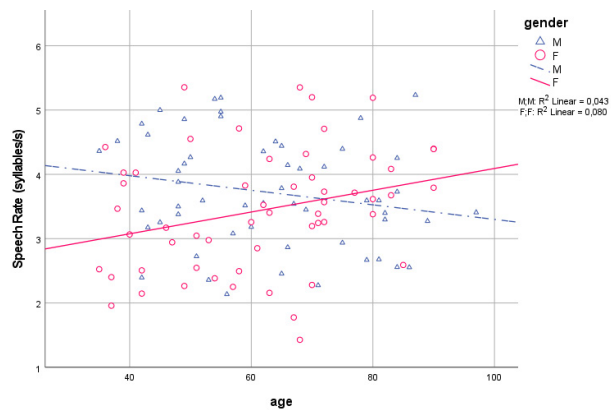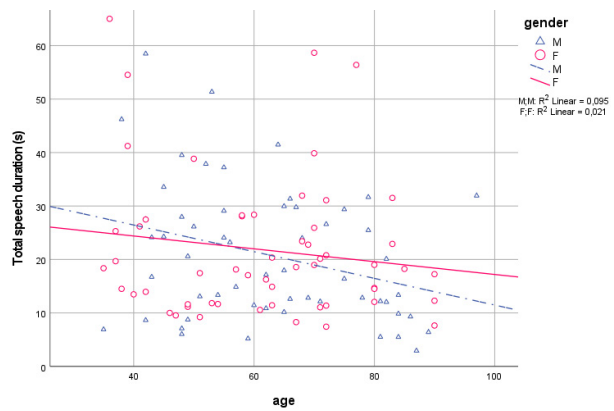

Figure 2: Scatterplot and regression lines for percent pause time by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

Figure 5: Scatterplot and regression lines for total speech duration by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

interval. The multiple linear regression revealed that, for both parameters, the age effect is only significant for men.

Regarding articulation rate (Figure 3): (1) age effect is gender dependent, with men presenting a 9.4% higher mean articulation rate than women; (2) difference between genders decreases with age, with older men and women presenting similar mean articulation rate, due to an increase in women's articulation rate. The regression model confirmed the gender differences and also showed a significant increase with age for female. Speech rate (Figure 4), as articulation rate, presented a tendency to increase in women. In men, a higher tendency to decrease, due to a rise in the percent pause time with age was observed.

Additionally, a decrease of the total speech duration with age, mainly in males was seen (Figure 5), which is in line with the significant decrease of the number of syllables also observed for males. For both genders, speech duration variability decreases with age, but is only significant in males.

4.2. Speaking f_0

In Figure 6 a large age effect in speaking f_0 was not observed. In men speaking f_0 tended to increase with aging. Conversely, in women speaking f_0 tended to slightly decrease with age. As expected, male speakers had a significantly lower speaking f_0 when compared to female speakers regardless of age.
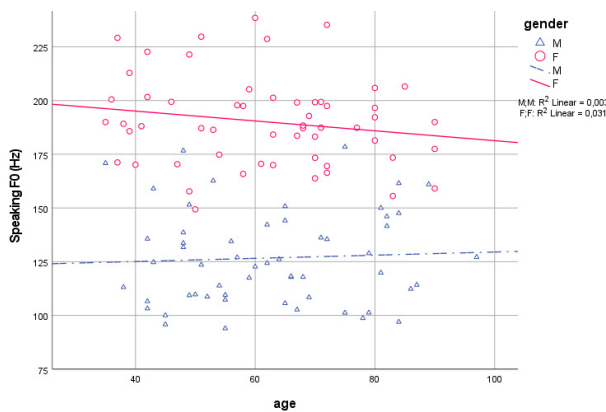
Figure 6: Scatterplot and regression lines for Speaking f_0 by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

4.3. Harmonics-to-Noise Ratio

As for HNR, as can be seen in Fig. 7, males presented lower values than females, and the regression results confirmed the gender differences. In the case of females, their values tended to be lower with age, while no change in males was observed. The regression line showed a decrease of about 4 dB between the ages 35 and 100 in females, which was significant.
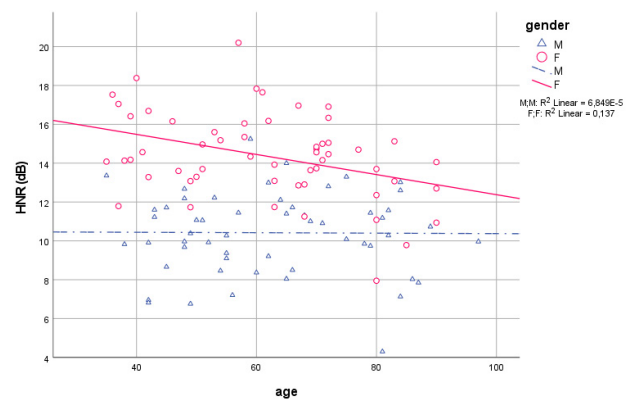
Figure 7: Scatterplot and regression lines for HNR by age and gender. Each symbol corresponds to one speaker. Solid line and circles: females; dashed line and triangles: males.

5. DISCUSSION

This study provides a base to complement previous studies in age effects, mostly at the suprasegmental level. The age effects in rhythmic parameters, speaking f_0 and HNR of the EP spontaneous speech were explored through a picture description task. Firstly, the older males produced shorter descriptions than younger adults, which may be related to task nature or indicate differences in linguistic domain (Mortensen, Meyer, & Humphreys, 2006).

Our analyses of rhythmic variation with age are in line with previous findings for other languages, mostly for men (Hartman & Danhauer, 1976; Steffens, 2011), where older men presented significantly more pause time and longer pause duration when compared with the young male speakers. Although men spoke faster than women, as in Jacewicz, Fox, & Wei (2010) and Verhoeven et al. (2004), this difference decreased with age. The faster articulation rate in older women is not in agreement with the general trend (Hazan et al., 2018; Linville, 2001), although some studies (Brückl & Sendlmeier, 2003; Jacewicz, Fox, O'Neill, & Salmons, 2009; Jacewicz et al., 2010) refer no age-related differences. Furthermore, a longitudinal study of spontaneous speech (Gerstenberg et al., 2018) also reported that articulation rate tends to increase in French speakers with age, presumably due to language specific effects or due to age-related changes in the cardiovascular system (i.e., older speakers may inhale more often, but may compensate for the reduced respiratory capacities by an increase in articulation rate to maintain information density) (Gerstenberg et al., 2018). Also, Brückl and Sendlmeier (2003) suggest that the duration of speech pauses is a better indicator of age than the articulation rate.

Additionally, for males, our results indicated that the total speech duration decreases with age, despite the fact that the mean speech duration of each speech interval only tends to decrease slightly. However, the speech duration variability significantly decreases with age, which may indicate that older males tend to perform speech intervals with a similar duration.

Regarding speaking f_0, our data tend to confirm the claim in the literature that f_0 slightly decreases in females with age (Goy et al., 2013; Guimarães & Abberton, 2005; Hazan et al., 2018; Morgan & Rastatter, 1986; Titze, 1994; Winkler, 2004), which has been attributed to the endocrinological changes that occur after menopause (Linville, 2001; Schötz, 2006; Sebastian, Babu, Oommen, & Ballraj, 2012). For males the speaking f_0 appears to remain stable with age, based on the regression lines. Nonetheless, the analysis of the same data by age groups in Albuquerque et al. (2021) revealed that speaking f_0 decreases until the age group [65-79] and starts to rise after that age, with an increase of about 10 Hz in the older group, which presented the highest mean value. Thus, a nonlinear variation of speaking f_0 with age, which has been reported in other studies (Titze, 1994), was also observed in the data. The increase of speaking f_0 in older males may be associated with the muscle atrophy, or with an increase in stiffness of vocal folds tissue with aging (Higgins & Saxman, 1991; Linville, 2001; Sebastian et al., 2012). Thus, speaking f_0 tends to converge across genders as age increases.

Lastly, females exhibit higher values of HNR than males, as in most studies (Ambreen et al., 2019; Dehqan et al., 2013; Goy et al., 2013; Schötz, 2006). The significant decrease of HNR with age in females is also consistent with past studies (Dehqan et al., 2013; Ferrand, 2002; Xue & Deliyski, 2001), and reflects more additive noise in the voiced signal (Dehqan et al., 2013; Ferrand, 2002; Schötz, 2006). According to Mueller (1997), a lower HNR would be predicted because hoarseness tends to be more prevalent in the voices of older speakers due to decrements in laryngeal function, such as ossification of cartilage, degeneration of muscle, connective tissue, and neural tissue, as well as respiratory changes (Dehqan et al., 2013; Mueller, 1997; Titze, 1994).

For males, almost no age-related variation was found in HNR, as in Ambreen et al. (2019), Dunashova (2021) and Goy et al. (2013). However, these results should be considered with caution, since the type of speech sample used in the present research did not consist of sustained vowels. Still, a longitudinal study (Dunashova, 2021), using reading samples of one male speaker at different ages (age 59 and age 74), found no changes in HNR with age.

Conclusions on the effects of aging on spontaneous speech should be drawn with caution due to differences in the recording environment, and because of the automatic extraction procedures. Although not all labeled syllables were manually verified, they were obtained using the same procedure for all speakers.

6. CONCLUSION

This article explores the age effects at the suprasegmental level in EP spontaneous speech. These results provide, essentially, a point of departure to establish the normal patterns of rhythm and intonation in spontaneous speech across age among adult Portuguese native speakers.

Fundamentally, as age progresses, male speakers tend to talk less, with a decrease in variability of speech interval duration and with higher pause time. Female participants present a significant increase in speech and articulation rate and also a HNR decrease, which means that women speak faster and with a lower voice quality.

Additional studies about HNR and articulation rate are required, and longitudinal studies might provide additional insights to the question of how getting older modifies the characteristics of spontaneous speech.

REFERENCES

Albuquerque, L., Oliveira, C., Teixeira, A., Sa-Couto, P., & Figueiredo, D. (2019). Age-related changes in European Portuguese vowel acoustics. *INTERSPEECH*, 3965–3969. Graz, Austria: ISCA. http://dx.doi.org/10.21437/Interspeech.2019-1818

Albuquerque, L., Oliveira, C., Teixeira, A., Sa-Couto, P., & Figueiredo, D. (2020). A comprehensive analysis of age and gender effects in European Portuguese oral vowels. *Journal of Voice*, In press.

Albuquerque, L., Oliveira, C., Teixeira, A., Sa-Couto, P., Freitas, J., & Dias, M. S. M. S. (2014). Impact of age in the production of European Portuguese vowels. *INTERSPEECH*, 940–944. Singapore. http://dx.doi.org/10.21437/Interspeech.2014-244

Albuquerque, L., Valente, A. R. S., Teixeira, A., Oliveira, C., & Figueiredo, D. (2021). Acoustic changes in spontaneous speech with age. *VIII Congreso Internacional de Fonética Experimental*, 3. Girona.

Ambreen, S., Bashir, N., Tarar, S. A., & Kausar, R. (2019). Acoustic analysis of normal voice patterns in Pakistani adults. *Journal of Voice*, 33(1), 124.e49-124.e58. http://dx.doi.org/10.1016/j.jvoice.2017.09.003

Barbosa, P. A. (2006). *Incursões em torno do ritmo da fala (Incursions around the rhythm of speech)*. Campinas: FAPESP/Pontes Editores.

Barbosa, P. A. (2010). Automatic duration-related salience detection in Brazilian Portuguese read and spontaneous speech. *Speech Prosody*. Chicago.

Barbosa, P. A. (2013). Semi-automatic and automatic tools for generating prosodic descriptors for prosody research. *TRASP*, 86–89. Aix-en-Provence. https://www.researchgate.net/publication/268278216

Bourbon, A., & Hermes, A. (2020). Have a break: Aging effects on sentence production and structuring in French. *12th International Seminar on Speech Production*.

Brückl, M., & Sendlmeier, W. (2003). Aging female voices: an acoustic and perceptive analysis. *VOQUAL'03*, pp. 163–168.

Cannizzaro, M., Harel, B., Reilly, N., Chappell, P., & Snyder, P. J. (2004). Voice acoustical measurement of the severity of major depression. *Brain and Cognition*, 56(1), 30–35. http://dx.doi.org/10.1016/j.bandc.2004.05.003

de Jong, N. H., & Wempe, T. (2009). Praat script to detect syllable nuclei and measure speech rate automatically. *Behavior Research Methods*, 41(2), 385–390. http://dx.doi.org/10.3758/BRM.41.2.385

Dehqan, A., Scherer, R. C., Dashti, G., Ansari-Moghaddam, A., & Fanaie, S. (2013). The effects of aging on acoustic parameters of voice. *Folia Phoniatrica et Logopaedica*, 64(6), 265–270. http://dx.doi.org/10.1159/000343998

Draxler, C., & Jänsch, K. (2017). *SpeechRecorder (3.12.0)*.

Dunashova, A. (2021). Intraspeaker variability of a professional lecturer: Ageing, genre, pragmatics vs. voice acting (Case study). *International Conference on Speech and Computer*, 179–189. http://dx.doi.org/10.1007/978-3-030-87802-3_17

Eichhorn, J. T., Kent, R. D., Austin, D., & Vorperian, H. K. (2018). Effects of aging on vocal fundamental frequency and vowel formants in men and women. *Journal of Voice*, 32(5), 644.e1-644.e9. http://dx.doi.org/10.1016/j.jvoice.2017.08.003

Escudero, P., Boersma, P., Rauber, A. S., & Bion, R. A. H. (2009). A cross-dialect acoustic description of vowels: Brazilian and European Portuguese. *J. Acoust. Soc. Am.*, 126(3), 1379–1393. http://dx.doi.org/10.1121/1.3180321

Ferrand, C. T. (2002). Harmonics-to-Noise Ratio: An index of vocal aging. *Journal of Voice*, 16(4), 480–487.

Gerstenberg, A., Fuchs, S., Kairet, J. M., Frankenberg, C., & Schröder, J. (2018). A cross-linguistic, longitudinal case study of pauses and interpausal units in spontaneous speech corpora of older speakers of German and French. *Speech Prosody*. http://dx.doi.org/10.21437/SpeechProsody.2018-43

Goodglass, H., & Kaplan, E. (1983). *The Assessment of Aphasia and Related Disorders* (2nd ed.). Philadelphia, PA.: Lea and Febiger.

Goy, H., Fernandes, D. N., Pichora-Fuller, M. K., & van Lieshout, P. (2013). Normative voice data for younger and older adults. *Journal of Voice*, 27(5), 545–555. http://dx.doi.org/10.1016/j.jvoice.2013.03.002

Guimarães, I., & Abberton, E. (2005). Fundamental frequency in speakers of Portuguese for different voice samples. *Journal of Voice*, 19(4), 592–606. http://dx.doi.org/10.1016/j.jvoice.2004.11.004

Hartman, D. E., & Danhauer, J. L. (1976). Perceptual features of speech for males in four perceived age decades. *J. Acoust. Soc. Am*, 59(3), 713–715. http://dx.doi.org/10.1121/1.380894

Hazan, V., Tuomainen, O., Kim, J., Davis, C., Sheffield, B., & Brungart, D. (2018). Clear speech adaptations in spontaneous speech produced by young and older adults. *J. Acoust. Soc. Am.*, 144(3), 1331–1346 https://doi.org/10.1121/1.5053218.

He, W., Goodkind, D., & Kowal, P. R. (2016). An aging world: 2015. *International Population Reports*, P95/16-1.

Hermes, A., Bourbon, A., & Cecile, F. (2020). Aging effects on prosodic structuring in French. *SPPL2020: 2nd Workshop on Speech Perception and Production across the Lifespan*, 119.

Hermes, A., Mertens, J., & Mücke, D. (2018). Age-related effects on sensorimotor control of speech production. *INTERSPEECH*, 1526–1530. Hyderabad. http://dx.doi.org/10.21437/Interspeech.2018-1233

Higgins, M. B., & Saxman, J. H. (1991). A Comparison of selected phonatory behaviors of healthy aged and young adults. *J Speech Hear Res*, 34(5), 1000–1010. http://dx.doi.org/10.1044/jshr.3405.1000

Jacewicz, E., Fox, R. A., O'Neill, C., & Salmons, J. (2009). Articulation rate across dialect, age, and gender. *Language Variation and Change*, 21(02), 233–256.

Jacewicz, E., Fox, R. A., & Wei, L. (2010). Between-speaker and within-speaker variation in speech tempo of American English. *J. Acoust. Soc. Am.*, 128(2), 839–850. http://dx.doi.org/10.1121/1.3459842

Kart, C. S., & Kinney, J. M. (2001). *The Realities of Aging : An Introduction to Gerontology*. Boston: Allyn & Bacon.

Linville, S. E. (2001). *Vocal Aging*. Australia, San Diego: Singular Thomson Learning.

Makiyama, K., & Hirano, S. (2017). *Aging Voice*. Singapore: Springer.

Martins, M. R. D. (1973). Análise acústica das vogais orais tónicas em Português. *Boletim de Filologia*, 22, 303–314.

Mautner, H. (2011). *A Cross-System Instrumental Voice Profile of the Aging Voice: With Considerations of Jaw Posture Effects*. University of Canterbury, New Zealand.

Morgan, E. E., & Rastatter, M. (1986). Variability of voice fundamental frequency in elderly female speakers. *Perceptual and Motor Skills*, 63(1), 215–218. http://dx.doi.org/10.2466/pms.1986.63.1.215

Mortensen, L., Meyer, A. S., & Humphreys, G. W. (2006). Age-related effects on speech production: A review. *Lang Cognitive Proc*, 21(1–3), 238–290. http://dx.doi.org/10.1080/01690960444000278

Mueller, P. B. (1997). The aging voice. *Seminars in Speech and Language*, 18(2), 159–168. http://dx.doi.org/10.1055/s-2008-1064070

Oliveira, C., Cunha, M. M., Silva, S., Teixeira, A., & Sa-Couto, P. (2012). Acoustic analysis of European Portuguese oral vowels produced by children. *IberSPEECH*, 328, 129–138. Madrid, Spain. http://dx.doi.org/10.1007/978-3-642-35292-8_14

Pakhomov, S. V. S., Kaiser, E. A., Boley, D. L., Marino, S. E., Knopman, D. S., & Birnbaum, A. K. (2011). Effects of age and dementia on temporal cycles in spontaneous speech fluency. *Journal of Neurolinguistics*, 24(6), 619–635. http://dx.doi.org/10.1016/j.jneuroling.2011.06.002

Pegoraro Krook, M. I. (1988). Speaking fundamental frequency characteristics of normal Swedish subjects obtained by glottal frequency analysis. *Folia Phoniatrica et Logopaedica*, 40(2), 82–90. http://dx.doi.org/10.1159/000265888

Pellegrini, T., Hämäläinen, A., de Mareüil, P. B., Tjalve, M., Trancoso, I., Candeias, S., … Braga, D. (2013). A corpus-based study of elderly and young speakers of European Portuguese: acoustic correlates and their impact on speech recognition performance. *INTERSPEECH*, 852–856. Lyon, Fance. http://dx.doi.org/10.21437/Interspeech.2013-241

Pellegrino, E. (2019). The effect of healthy aging on within-speaker rhythmic variability: A case study on Noam Chomsky. *Loquens*, 6(1), e060. http://dx.doi.org/10.3989/loquens.2019.060

Pellegrino, E., He, L., & Dellwo, V. (2018). The effect of ageing on speech rhythm: A study on Zurich German. *Speech Prosody*, 133–137. http://dx.doi.org/10.21437/SpeechProsody.2018-27

Ramig, L., & Ringel, R. (1983). Effects of physiological aging on selected acoustic characteristics of voice. *J Speech Hear Res*, 26(1), 22–30. http://dx.doi.org/10.1044/jshr.2601.22

Rojas, S., Kefalianos, E., & Vogel, A. (2020). How does our voice change as we age? A systematic review and meta-analysis of acoustic and perceptual voice data from healthy adults over 50 years of age. *JSLHR*, 63(2), 533–551. http://dx.doi.org/10.1044/2019_JSLHR-19-00099

Schötz, S. (2006). Perception, analysis and synthesis of speaker age. In *Travaux de l'Institut de Linguistique de Lund* (Vol. 47). Lund University: Linguistics and Phonetics.

Schuller, B., Steidl, S., Batliner, A., Burkhardt, F., Devillers, L., Müller, C., & Narayanan, S. (2013). Paralinguistics in speech and language - State-of-the-art and the challenge. *Computer Speech and Language*, 27, 4–39. http://dx.doi.org/10.1016/j.csl.2012.02.005

Sebastian, S., Babu, S., Oommen, N. E., & Ballraj, A. (2012). Acoustic measurements of geriatric voice. *Journal of Laryngology and Voice*, 2(2), 81–84. http://dx.doi.org/10.4103/2230-9748.106984

Smith, B. L., Wasowicz, J., & Preston, J. (1987). Temporal characteristics of the speech of normal elderly adults. *J Speech Hear Res*, 30(4), 522–529. http://dx.doi.org/10.1044/jshr.3004.522

Stathopoulos, E. T., Huber, J. E., & Sussman, J. E. (2011). Changes in acoustic characteristics of the voice across the life span: measures from individuals 4–93 years of age. *J Speech Lang Hear Res*, 54(4), 1011–1021. http://dx.doi.org/10.1044/1092-4388(2010/10-0036)

Statistics Portugal. (2015). Envelhecimento da população residente em Portugal e na União Europeia (Aging of the resident population in Portugal and the European Union). *Destaque: Informação à Comunicação Social*.

Statistics Portugal. (2019). Estimativas de População Residente em Portugal - 2018 (Estimates of resident population in Portugal - 2018). *Destaque: Informação à Comunicação Social*.

Steffens, Y. (2011). *The Aging Voice*. GRIN Verlag.

Titze, I. R. (1994). Voice classification and life-span changes. In *Principles of Voice Production* (pp. 169–190). Englewood Cliffs, New Jersey: Prentice Hall.

Tuomainen, O., Hazan, V., & Taschenberger, L. (2019). Speech communication in background noise: Effects of aging. *19th International Congress of the Phonetic Sciences*, 805–809. Australasian Speech Science and Technology Association Inc.

United Nations Department of Economic and Social Affairs Population Division. (2019). *World Population Ageing 2019: Highlights*.

Verhoeven, J., De Pauw, G., & Kloots, H. (2004). Speech rate in a pluricentric language: A comparison between Dutch in Belgium and the Netherlands. *Language and Speech*, 43(3), 297–308. http://dx.doi.org/10.1177/00238309040470030401

Vipperla, R., Renals, S., & Frankel, J. (2010). Ageing voices: The effect of changes in voice parameters on ASR performance.

EURASIP J. Aud. Speech Music Process, 1–10. http://dx.doi.org/10.1155/2010/525783

Volín, J., Tykalová, T., & Bořil, T. (2017). Stability of prosodic characteristics across age and gender groups. *INTERSPEECH*, 3902–3906. http://dx.doi.org/10.21437/Interspeech.2017-1503

Winkler, R. (2004). Open Quotient and breathiness in aging voices-changes with increasing chronological age and it's per-

ception. *German-French Summerschool on "Cognitive and Physical Models of Speech Production, Perception and Perception-Production Interaction."* Lubmin.

Xue, S. A., & Deliyski, D. (2001). Effects of aging on selected acoustic voice parameters: preliminary normative data and educational implications. *Educational Gerontology*, *27*(2), 159–168.