Voice quality and gender: some insights on correlations between perceptual and acoustic dimensions

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Abstract

The present study aims at characterizing, from the perceptual and acoustic points of view, differences in voice quality settings related to gender. The corpus was composed by speech samples recorded by 38 subjects (19 male and 19 female), aging from 20 to 58 years-old. The audio samples were analyzed in PRAAT by means of the SG Expression Evaluator Script, which extracts f0 and f0 first derivate, intensity, spectral slope and long-term average spectrum measures. The same samples were perceptually evaluated by means of the Vocal Profile Analysis Scheme. The acoustic measures and voice quality settings judgments were statistically analyzed by means of discriminant analysis and cluster agglomerative hierarchical analysis procedures. The statistical data showed the power of f0 and spectral slope measures as well as the influence of some supralaryngeal voice quality settings in differentiating speaker`s gender. Gender was found to be an influential variable.

Index terms: *Speech Acoustics; Voice Quality; Perception; Statistical Analysis; Extralinguistic Factors.*

1. Introduction

The description of correspondences between perceived voice quality and long-term acoustic correlates is not an easy task, but it can provide a detailed description of events related to voice quality settings in laryngeal, supralaryngeal and tension domains. This paper addresses this demand, applying a method for the approach of perceptual and acoustic correlates that could bring some insights on the singularities of male and female voices.

In a previous study [1], the authors investigated the power of some acoustic measures to predict voice quality settings. The methodological procedures, based on multivariate statistical approach, made it possible to identify the clusters related to the acoustic measures group and the perceptual judgements as well as to correlate these two groups by means of canonic correlation analysis. In that study some of the findings indicated that gender might be an influential variable, regarding the interaction of supralaryngeal (tongue, pharynx and larynx height), laryngeal (phonatory) and tension settings, as well as f0 and intensity measures.

The present study aims at investigating the interaction between settings and acoustic measures further and introduces gender as a variable.

The detailed description of acoustic characteristics and their discriminatory power to predict perceived voice quality settings [2-3] is still a challenge in prosodic research.

One of the challenges refers to the selection of the perceptual evaluation, since traditional protocols and scales for voice quality evaluation do not model the events detected by the listener and comprise only a small set of parameters which do not necessarily address the overall voice quality description [5]. Another challenge is the investigation of acoustic and physiologic correlates of the perceptual findings in order to validate them and to describe the set of parameters comprised in specific voice quality descriptors as grouped in multidimensional scales [6,7].

The phonetic description of voice quality model provides an analytical, scientific and integrative approach of voice quality [2] that substantiate the Vocal Profile Analysis Scheme (VPAS) [3,7]. Some of our previous reports on perceptual description of voice quality [1, 4, 8] are based on material developed with the purpose of introducing the Vocal Profile Analysis Scheme - VPAS in the Brazilian Portuguese context (BP-VPAS) [9]. The building of the corpus took into account the principle of susceptibility of segments to the effects of voice quality proposed by Laver [2] and made use of the keyspeech segments [3,9].

For the sake of describing the acoustic correlates of perceived voice quality settings, the option was a set of f0, intensity and spectral parameters measured in a long-term basis, by means of the SG Expression Evaluator Script (SG-EES) [10]. This procedure allowed to collect much information from the corpus designed for voice quality evaluation [9]. The ultimate task was to find some procedure to analyze the database generated by perceptual and acoustic procedures [1,4,8,9].

Following this line of investigation, this study aims at characterizing, from perceptual and acoustic points of view, differences in voice quality settings and in acoustic measures related to gender. Its originality stems from two factors: the set of acoustic parameters made available by the use of the SG-EES and the kinds of statistical analyses applied [1,4,8,11].

Report on gender distinction in terms of acoustic descriptions can be found [12], as respect to long-term average spectrum (LTAS) analysis. Some comprehensive approach on perceptual and acoustic correlates for laryngeal activity are also available [6,13,14], but supralaryngeal and tension settings are not usually addressed.

As studies focusing voice quality are rather incipient in the prosodic field, the results may stimulate voice quality approaches in the domains of vocal expressiveness [10,15,16,17,18], voice disorders [6,7,19,20] and crosslinguistic studies [7,21,22].

2. Methods

The corpus was composed by semi-spontaneous speech samples and repetitions of 10 key-sentences samples designed for the purpose of phonetic voice quality evaluation [9], recorded in a radio studio by 38 subjects (from 20 to 58 years old, 19 males and 19 females). Data were paired (age and gender), that is, the same number of men and women at all ages concerned.

The audio samples, comprising 696 utterances, were analyzed by means of the SG- EES [10], a revised version of the script, running in the software PRAAT, which automatically extracts acoustic measures: f0 (median, inter-quartile semi-amplitude, skewness and 99,5% quantile) and its first derivate (mean, standard-deviation (SD) and skewness), intensity (skewness), spectral slope (mean, SD and skewness) and LTAS (SD).

The same samples were perceptually evaluated based on the Vocal Profile Analysis Scheme for Brazilian Portuguese: BP-VPAS [4,8,9] by two phoneticians, experts in the use of the profile. The voice quality settings judgments and acoustic measures were statistically analyzed by means of discriminant analysis and cluster agglomerative hierarchical analysis [11] to search for the capability of perceptual and acoustic data to discriminate the speaker´s gender. The discriminant analysis was applied to perceptual and acoustic data firstly separately and, then, grouped. The Wilks Lambda Test was applied to search for the determinant factors in gender discrimination (assuming $p<0,0001$). The cluster agglomerative hierarchical analysis was applied distinctively for perceptual, acoustic data and both, as well for male and female distinctively and grouped.

To derive the statistical measures the s*oftware* Xlstat from Addinsoft was used.

This project was approved by Ethics Committee (101/11).

3. Results

The results show some correlations between the perceived voice quality settings and acoustic measures that differ from male and female data.

Discriminant analysis revealed a total segregation (100%) between male and female as regard to acoustic measures. In a decreasing scale, the most influent acoustic measures, and their respective correlation factors, were: f0 (interquartile semi-amplitude: 0,9999, median: 0,8834, quantile 99,5%: 0,3741, skewness: 0,2424) and spectral slope (mean: 0,2256 and SD: 0,1859), f0 first derivate (mean: 0,0974), intensity (skewness: 0,0738), spectral slope (skewness: 0,0669), LTAS (SD: 0,0567), f0 first derivate (skewness: 0,0160, SD: 0,0149).

The mean acoustic values for f0, first f0 derivate, intensity, spectral slope and LTAS for male and female speakers are presented in table 1.

Table 1. *Mean acoustic measures (f0, first f0 derivate, intensity, spectral slope and LTAS- Expression Evaluator Script) concerning male and female speakers*

Acoustic measures	f0 median (Hz)	f0 interquartile semi-amplitude (Hz)	f0 quantile 99,5%	f0 skewness
Male	127,22	59,18	0,40	0,10
Female	207,55	120,82	1,06	0,06
P value	< 0,0001	< 0,0001	< 0,0001	< 0,0001
Lambda	0,220*	0,000*	0,860*	0,945 *
Acoustic measures	1st f0 derivate mean	1st f0 derivate SD	1st f0 derivate skewness	Intensity skewness
Male	-0,05	0,015	-0,07	6,64
Female	-0,23	0,014	-0,17	7,18
P value	0,010	0,695	0,674	0,052
Lambda	0,991	1,000	1,000	0,995
Acoustic measures	Spectral slope Mean (dB)	Spectral slope SD (dB)	Spectral slope skewness	LTAS SD (dB)
Male	2,36	2,85	1,30	13,62
Female	2,65	3,09	1,31	13,29
P value	< 0,0001	< 0,0001	0,078	0,135
Lambda	0,949*	0,965*	0,996	0,997

* Statistical relevance (Wilks Lambda Test)

For the perceptual data, the segregation of variable was partial (91,9% for female and 92,2% for male). In a decreasing scale, the most influent voice quality settings, and their respective correlation factors values (considering those superior to 0,2000): were nasal (0,3230), pharyngeal expansion (0,3145), labiodentalization (0,3023), creaky voice (0,2690), retracted tongue tip (0,2548), modal voice (0,2539), tongue body (advanced: 0,2416 and lowered: 0,2347), jaw -extensive range (0,2153); vocal tract hypofunction (0,2132), lip rounding (0,2109), jaw -minimized range (0,2083) and falsetto (0,2004) settings.

The distribution of voice quality settings for male and female speakers are presented in Figure 1.

VOICE QUALITY SETTINGS		MALE	FEMALE
Supra-Laryngeal	Lips	Rounding Spread Extensive range Minimized range	Labiodentalization **Spread** **Extensive range** **Minimized range**
	Jaw	**Open** Closed Minimized range Protruded	Open Extensive range **Minimized range**
	Tongue tip	**Advanced**	Advanced Retracted
	Tongue body	**Advanced** Retracted **Lowered** **Minimized range**	Advanced **Retracted** Lowered Minimized range
	Velopharyngeal	**Nasal** **Audible nasal escape** **Denasal**	Nasal Audible nasal escape Denasal
	Pharynx	**Constriction**	Expansion Constriction
	Larynx height	Raised Lowered	**Raised** **Lowered**
Tension	Vocal Tract	Hypofunction **hyperfunction**	**Hypofunction** hyperfunction
	Larynx	Neutral	hypofunction
Phonatory (modes of vocal folds vibration)		Modal Whisper Breathy voice **Harsh voice** **Creaky voice**	**Modal** **Whisper** **Breathy voice** Harsh voice Creaky voice Falsetto

Figure 1. Voice quality settings detected on VPAS-PB evaluation for male and female speakers (**bold** marks indicate the prevalence of the voice quality settings by gender)

Data from Wilks Lambda Test are presented at Table 2, as related to that voice quality settings relevant to distinguish male and female groups.

Table 2. *Prevalence of voice quality settings detected on VPAS-PB evaluation for male and female speakers (**bold** marks indicate the prevalence by gender)*

Voice quality settings	Nasal	Pharyngeal Expansion	Labio-dentalization	Creaky Voice
Group	**M**,F	F	F	**M**,F
P value	< 0,0001	< 0,0001	< 0,0001	< 0,0001
Lambda	0,926*	0,930*	0,935*	0,949*
Vocal tract settings	Retracted tongue tip	Modal	Advanced tongue body	Lowered tongue body
Group	F	M,**F**	**M**,F	**M**,F
P value	< 0,0001	< 0,0001	< 0,0001	< 0,0001
Lambda	0,954*	0,954*	0,959*	0,961*
Vocal tract settings	Jaw-Extensive Range	Vocal Tract Hypofunction	Lip Rounding	Jaw-Minimized range
Group	F	F	M	M,**F**
P value	< 0,0001	< 0,0001	< 0,0001	< 0,0001
Lambda	0,967*	0,968*	0,969*	0,969*
Vocal tract settings	Falsetto	Closed Jaw	Audible Nasal Escape	
Group	F	M	**M**,F	

P value	<0,0001	< 0,0001	< 0,0001
Lambda	0,972*	0,973*	0,978*

* Statistical relevance (Wilks Lambda Test). M: Male, F: Female

Information regarding data from The Wilks Lambda Test indicated the order of factors that established the boundaries between male and female groups (in a decreasing scale). Table 1 displays results from the acoustic analysis and table 2 those from the perceptual analysis of voice quality settings. The relevant parameters were: f0 interquartile semi-amplitude, f0 median, f0 quantile 99,5%, f0 skewness, spectral slope- mean and SD. The relevant voice quality settings were: nasal, pharyngeal expansion, labiodentalization, creaky voice, retracted tongue tip, modal, advanced tongue body, lowered tongue body, jaw- extensive range, vocal tract hypofunction, lip rounding, jaw-minimized range, falsetto, closed jaw and audible nasal escape settings.

Discriminant analysis applied to both perceptual and acoustic data revealed a total segregation between male and female samples (100%). The acoustic data were prevalent to perceptual in this analysis.

The most influent parameters (grouping acoustic and perceptual variable), and respective correlation factors, were: f0 acoustic measures (interquartile semi-amplitude: 0,9999, median: 0,8834, quantile 99,5%:0,3740); nasal (0,3230), pharyngeal expansion (0,2645) and labiodentalization (0,0,2543) settings; f0 measure (skewness: 0,2424); creaky voice (0,2263) setting; spectral slope (mean: 0,2255); retracted tongue tip (0,2143), modal (0,2539) and advanced tongue body (0,2033) settings.

The discriminant analysis also allowed correlations intragroups (acoustic and perceptual variable). For acoustic data, correlations were found between LTAS-SD and spectral slope-median (0,978); f0 interquartile semi-amplitude and f0 median (0,866) and f0 first derivate-SD and f0 quantile 99,5% (0,775). In the perceptual domain, the correlations were between the following pairs of settings: jaw-extensive range and lips- extensive range (0,737); pharyngeal constriction and closed jaw (0,694); and vocal tract hyperfunction and pharyngeal constriction (0, 602).

Concerning male speech samples, the cluster analysis applied to the acoustic data yielded three classes (Class 1: f0-median, Class 2: f0-interquartile semiamplitude and Class 3 comprised all other acoustic measures), being class 3 distant from classes 1 and 2. The same distribution was found for female samples.

Concerning the male speech samples, the cluster analysis applied to the perceptual data yielded four classes, one of them, Class 1, comprising a large set of parameters. Classes 2 and 3 were separated from classes 1 and 4. Class 2 included open jaw, lowered tongue body, lowered larynx and creaky voice settings. Class 3 grouped advanced tongue tip, tongue body-minimized range, audible nasal escape, nasal and modal settings. Class 4 grouped raised larynx, laryngeal hyperfunction and harsh voice settings.

Concerning the female speech samples, the cluster analysis applied to perceptual data yielded five classes, one of them comprising a large set of parameters (Class 1). Classes 4 and 5 segregated from others, and classes 2 and 3 were very close to each other. Class 4 comprised pharyngeal expansion and lowered larynx settings and Class 5 laryngeal hyperfunction setting. Class 3 grouped jaw - minimized range, retracted tongue tip and tongue body and modal voice settings. Class 2 was represented by labiodentalization setting.

Concerning the male and female speakers, the cluster analysis applied to perceptual data generated 8 classes, which were basically segregated by classes 2 (open jaw, lowered tongue body and creaky voice), 6 (lowered larynx) and 7 (laryngeal hyperfunction). The acoustic data distribution was the same for both groups.

Concerning the total set of parameters (perceptual and acoustic) for both male and female speakers, the cluster analysis yielded 16 classes, in which the most prominent classes were 1 (f0 median) and 2 (interquartielsemi-amplitude) representing acoustic measures and Class 13 (advanced tongue tip, audible nasal escape and nasal settings) representing the perceptual data.

The variable significant in terms of great segregation of elements is presented as the result of cluster analysis for male, female and both groups. From the acoustic point of view, male samples were better described by f0 values, specially median and interquartile semi-amplitude, as well for female speakers and, consequently, for the grouped analysis.

4. Discussion/Conclusions

This study introduced an innovative approach to the investigation of voice qualities which comprised the use of the SG Expression Evaluator Script [10] to extract acoustic measures, the application of the VPAS [4, 9] to describe voice quality settings and a multivariate statistical approach applied to a large set of data.

Correlations between variables (types of settings and acoustic measures; types of settings and gender; acoustic measures and gender) were identified by means of discrimination analysis.

A large amount of data was taken into account. This is relevant, considering that an index of statistical significance derived from the analysis of a limited set of data may not guarantee correlation between variables has been obtained. In this study, the results of discriminant analysis indicate that male and female speech samples were segregated.

The prevalent acoustic variables, in a decreasing scale of influence, were: f0 median (as expected); f0 variability (interquartile, semi-amplitude, quantile 99,5% and skewness); spectral slope (mean and SD).The most prevailed perceptual variables were: supralaryngeal settings (labial, nasal and pharyngeal); and phonatory settings (creaky voice).

From the perceptual point of view, the following supralaryngeal voice quality settings were identified: velopharyngeal (expansion); labial (labiodentalization); tongue tip (retracted); tongue body (advanced and lowered) and jaw (minimized and extensive range). These were combined with some phonatory (creaky and modal voices) and vocal tract (hypofunction and hyperfunction) settings.

These data complement some descriptions that focused primarily on phonatory activity [6,12-14,19,20] and highlight the interaction between laryngeal, supralaryngeal and tension dimensions in determining the perceived voice quality.

The cluster analysis showed similar tendencies to the discriminant analysis. The influence of interquartile semi-amplitude and median f0 values indicated that the f0 variability during speech is crucial to measure voice quality. In [1,4] the relevance of f0 and first f0 derivate measures in predicting perceived voice quality was pointed out. It was found out that the smaller the f0 variability, greater was the possibility of a modal setting occur. On the other hand, the greater the f0 variability, the greater the possibility of laryngeal tension and phonatory settings with aperiodicity (harsh, whispery and creaky voice) [1].

This level of interaction can be interpreted as follows: some actions concerned with the reduction of the total extension of the vocal tract and the narrowing of some resonator cavities can negatively influence vocal fold vibration patterns and affect f0 and spectral slope values. The opposite effects, elongation of the extension of the vocal tract and the expansion of the resonator cavity area also related to f0 and spectral slope measures. It is important to point out that the lower the larynx, the more lax is the contact between vocal folds [23] and that directly affects the spectral slope [6,12,13,14].

Some intragoup correlation factors derived from variable importance test in discriminant analysis reinforce these interactions, such as, in the perceptual domain, the association of pharyngeal constriction and closed jaw or vocal tract hyperfunction and pharyngeal constriction settings and the association of extensive range of lips and jaw. The important variable associations between acoustic factors comprised spectral slope (mean) and LTAS (SD), f0 interquartile, semi-amplitude and f0 (median); f0 (quantile 99,5%) and 1^{st} f0 derivate (SD).

The f0 interquartile semi-amplitude measures were dominant in determining speaker´s gender. This finding reinforce the demand for carefully conducted experiments aimed at investigating long-term f0 variability measures [10]. The same demand is claimed for spectral measures (such as intensity, spectral slope and overall LTAS).

Contrasting clusters of supralaryngeal voice quality were found: pharyngeal expansion combined with lowered larynx for female voices and open jaw, lowered tongue body and creaky voice for male voices. These combinations can be thought in terms of the frequency code [23] and explored in future speech expressiviness studies. These associations also reinforce the physiological principle of compatibility between settings, as described by John Laver [2] and have been previously detected [1,4,8,16].

The tendency towards reducing or constricting cavities in some female voices was related to laryngeal hyperfunction settings, which also can be related to some inherent laryngeal configuration characteristics, such as the tendency of a posterior glottal shrink during phonation [6,12,19]

Finally, gender was found to be an influential variable in clustering groups of supralaryngeal voice quality settings and f0 and spectral slope acoustic measures.

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