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Differences in Voice Quality Between Men and Women: Use of the Long-Term Average Spectrum (LTAS)

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Summary: The goal of this study was to determine if there are acoustical differences between male and female voices, and if there are, where exactly do these differences lie. Extended speech samples were used. The recorded readings of a text by 31 women and by 24 men were analyzed by means of the Long-Term Spectrum (LTAS), extracting the amplitude values (in decibels) at intervals of 160 Hz over a range of 8 kHz. The results showed a significant difference between genders, as well as an interaction of gender and frequency level. The female voice showed greater levels of aspiration noise, located in the spectral regions corresponding to the third formant, which causes the female voice to have a more "breathy" quality than the male voice. The lower spectral tilt in the women's voices is another consequence of this presence of greater aspiration noise. **Key Words:** Long-Term Average Spectrum—Voice quality—Gender differences—Breathiness—Aspiration noise—Spectral tilt.

The ability of the human ear to identify an individual's gender on the basis of voice quality, regardless of linguistic content, has been discussed previously by various investigators (1,2). Yet, the perceptual parameters or various strategies used to discriminate between male and female voices are not well understood. O'Kane (1) believes that this discrimination appears to be performed routinely by human listeners by extracting a limited number of perceptual cues; these may include various sociological factors such as cultural stereotyping. However, Murray and Singh (3) have suggested that listeners are able to distinguish a speaker's gender on the basis of such acoustic characteristics as stress and pitch levels, in addition to nasality versus hoarseness in male and female voices, respectively.

In speech studies involving gender identification, the acoustic correlates usually submitted to judgments of listeners have been related to a set of laryngeal and supralaryngeal parameters. Regarding the laryngeal variables, the importance given to the fundamental frequency (F_0) as an indicator of the speaker's sex is noteworthy (4–7). The woman's pitch has a higher frequency value than the man's pitch, although the absolute values of this difference are in question. Depending on the study, woman's pitch is higher by as much as 0.45 times (8) to 1.7 times (9) and even to an octave (10). Given that an inverse relation exists between the mean F_0 and the membranous vocal fold's length, the physiological substratum appears to reside in the greater length of the male vocal folds (11). Daniloff et al. (12) stated, "An individual's modal frequency is governed in large part by the physical size, shape, and mass of vocal folds and larynx. Also in part, our vocal habits and training accustom us to select a frequency range that is comfortable, so that modal frequency is the result of a compromise between personal habit and optimum mechanical buzz frequency" (pp. 203–4). Nevertheless, some sociolinguistic studies have suggested that these differences in voice quality across sexes may be due more to

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sociocultural than to physiological factors, since listeners are able to distinguish between male and female voices even when the speakers are children (i.e., when the speaker's laryngeal physiology may be identical across sexes) (13).

Regarding variables of the vocal tract's resonance (VTR), research is even more scarce. Early research considered that the vocal tract's contribution to the perception of the speaker's gender lay in the formants frequencies (14). Bladon (15) detected that the vowels emitted by men presented narrower formant bandwidths with a less profound drop (a flatter profile) in the spectrum than the vowels generated by women. Others have suggested that there is a greater amplitude of the first harmonic compared with the second in the female voice, as opposed to that of the male voice (9,16). However, this difference may come from the interaction between F_0 and harmonic structure. Klatt and Klatt (9) have suggested that the voice differentiation between the sexes comes from the generation of a noisier aspiration in women's larynxes compared with that in men. These greater levels of aspiration noise, centered in the high-frequency spectral regions corresponding to the third formant, make the female voice present a more "breathy" quality than the male voice (17). As a consequence of this aspiration noise in high frequencies, it can be expected that the source spectrum has a lower spectral tilt, given that upon increasing the aspiration noise in the third formant, the general spectral tilt is slower. Löfqvist and Manderson (18), using the Long-Term Average Spectrum (LTAS) as an analytic procedure, determined this overall tilt of the source spectrum through the ratio of energy between 0–1 and 1–5 kHz. However, Klatt and Klatt (9) established a greater spectral drop in "breathy" voice down to ~2 kHz (−18 dB/octave in breathy vowels compared with −12 dB/octave in laryngealized and modal vowels), maintaining the aspiration noise from that frequency onwards. The differences between the establishment of the type of spectral drop proposed by both authors and probably due to the fact that Löfqvist and Manderson (18) centered their investigation on pathological voices rather than on normal voices as in the Klatt and Klatt study (9).

Despite the great body of knowledge that has progressively accumulated concerning the differences between the anatomy, physiology, and acoustics of male and female voices, very few attempts have been made to classify both types of voices by means of objective acoustic measures, with the exception of the studies by Childers et al. (19,20), Childers and Wu (21), and Wu and Childers (2). Following the line of these investigators, we tried to discover the acoustical differences between male and female voices by means of the mid-to-long averaging techniques, as the LTAS. This type of analysis has proven to be most valuable as an averaging measure because it looks at long speech segments and disregards linguistic contents.

Besides, there are very few studies that base male and female voice differentiations on long-term averaging measures. Tarnóczy and Fant (22) compared the spectra of male and female Hungarian, Swedish, and German speakers with the objective of studying the differences in the LTAS due to variations among these languages. Although the results were confusing with respect to the main objective, Tarnózky and Fant (22) were able to detect differences across sexes in the different languages. The above-mentioned differences centered in the 0.7–1.5 kHz range for male speakers, and in the 1–2 kHz range for women. The differences between speakers' sex were greater than expected.

In another study, Schlorhaufer et al. (23) compared the LTAS of different genders and age groups. Five men, five women, and five children, all German speakers, were studied. Although the spectra of these subject groups demonstrated differences, the researchers did not attempt to quantify these differences. Wu and Childers (2) conducted a study aimed at establishing different templates for both sexes, stating that gender information should be invariant, phoneme independent, and speaker independent for a given gender. They added that these conditions can be better ensured by employing long-term averaging measures. Following their suggestions, we believe that averaging measures, such as LTAS, emphasize the specific information of each subject's gender.

Improvement of the systems of synthesis of the female voice has been one of the major goals of previous studies using methodological procedures similar to ours. That is the reason for studying in depth the objective acoustic differentiation between male and female voices. Given that the majority of current voice synthesizers function with male voices, it is difficult to obtain voice synthesis of women's or children's voices with an acceptable level of naturalness. According to Titze (11), this may be due to the fact that the main parameter utilized in the generation of synthesized voices has been the F_0. However, the differential synthesis of male and female voices implies much more than a mere scale of F_0, and some basic differences in the phonatory and articulatory mechanisms need to be considered. Titze's suggestion leads one to believe that a great advance in the acoustic differentiation of male and female voices is required in order to improve the current systems of analysis and synthesis of both genders' voices. Klatt and Klatt (9) stated that the principal difficulty in achieving this objective stemmed from the diversity of acoustic indexes employed in the majority of the studies. Acoustic phonetics has established the frequency distribution of formants as the relevant variable in the identification of sounds, generally doing so by specifying a formant's frequency for its central value. The determination of these central values becomes more difficult as the fundamental value is increased. Due to the existence of the higher level in the F_0 voices of women and children, the systems of analysis lose resolution, which impedes the evaluation of the formant's frequency points in these cases (24). Furthermore, the informal observations of Klatt (17) suggest that the vocal spectra obtained from female voices do not completely conform to the all-pole model, possibly because of their tracheal joint and source–filter interactions. Titze (11) questions whether the source–filter theory of speech production would have followed the same development if the earlier models had been based on female voices.

In the present study, we first attempted to determine, by means of the LTAS, if a spectral profile characteristic of a speaker's gender exists and, if so, to delineate the existing differences between male and female voice profiles obtained by this method. Second, we sought to demonstrate that the differences between both types of voices can be attributed to the existence of aspiration noise in the spectral regions corresponding approximately to the third formant. As described earlier (9), it is believed that this causes female voices to be emitted with a more "breathy" quality than that of male voices.

METHOD

Subjects

Fifty-five subjects (24 men and 31 women), whose ages ranged from 20 to 50 years (with an average of 28 and 30 years, respectively), participated voluntarily in this study. All subjects were native Spanish speakers. None had a history of speech or auditory problems, and none suffered from colds or respiratory infections during the length of their involvement in the study. The voices of all subjects were determined to be normal (nondysphonic) by two expert speech–language pathologists.

Experimental task

The experimental task involved the reading of a standard text, taken from the Spanish translation of Lewis Carroll's *Alice in Wonderland,* which lasted ~3 minutes and was composed of three paragraphs. The subjects were instructed to read the text in their natural voice and at a normal speed. All recording samples took place in a soundproof room at the University of Granada's Voice Laboratory. The recording microphone was held at a distance of 20 cm from the mouth, in order to avoid possible aerodynamic interferences (25).

Apparatus

The recording was performed with an AKG D 222 EB microphone with a flat response and a SONY 77 ES Digital Audio Tape (DAT) with a sampling frequency of 48 kHz, keeping the volumen of the DAT between −30 and −20 dB. The voice samples were introduced via a direct connection to a DSP Sona-Graph, model 5500 (Kay Elemetric), and were analyzed with the LTAS portion of the Voice Analysis Program. LTAS calculates a power magnitude spectrum across the frequency range of the input signals. LTAS is different from the power spectrum in that it includes only voiced segments, and it continuously averages the input signal for 30–90 s. The advantage of screening out unvoiced signals is that these unvoiced signals may corrupt the average of the voiced segments, and it can mask the information of the voice source (18). The LTAS program screens the input signal for voiced information based on a simple zero-crossing and energy criteria (26). The program was adjusted to include spectra of voice signals, and its discrete power spectrum was added to the accumulated average. The program will not include spectral signals if voicing is in doubt.

The following elements were selected for the analysis: a frequency range of 8 kHz, an input shaping in FLAT, maintenance of the memory's channel at 38 s, a transform size of 128 points, the channel sensitivity at 45 dB, and the AC-coupled option.

Acoustic analysis

The acoustic analysis was conducted with the second paragraph of the text in order to avoid any influence of possible vacillations at the beginning of the reading and any fall in intensity or intonation at the end of the text.

The analysis was performed on the amplitude values, in decibels, at intervals of 160 Hz, thus, obtaining a total of 50 measurements for each subject, corresponding to the values, which in turn corresponded to each of the frequency levels in the total range of 8 kHz (0.160, 0.320, 0.480, 0.600 . . . 8 kHz).

RESULTS

For evaluating the possible differences in the distribution of energy between the male and female spectra and, as such, to assess at what frequencies they may exist, an analysis of variance (ANOVA) 2 × 50 was conducted. The analysis began with the gender factor (G) at two levels, male and female, and the frequency level factor (L) in kHz, along 50 frequency levels. The amplitude, measured in decibels, was analyzed as the dependent variable. Figure 1 presents the means in each frequency level. The results of the ANOVA are shown in Table 1. A significance level of 0.05 in the sex factor and a level of 0.001 in the level frequency factor were used. As Table 1 shows, there was a significant main effect for the sex factor [$F(1,53) = 6678$; $p < 0.013$]. Likewise, the main effects for the level frequency factor were significant [$F(49,257) = 1509.978$; $p < 0.001$]. Significant differences were also seen in the interaction between these two factors S × L [$F(49,2597) = 9.336$; $p < 0.001$].

Given the first objective of the study, the significant interaction differences between speakers' voices according to sex were analyzed with a one-way ANOVA for each frequency level. The results indicated that the spectral amplitude of women's voices is greater ($p < 0.001$) in the following frequency levels: 0.8, 0.96, 2.88, 3.04, 4.16, 4.32, 4.48, 4.64, 4.80, and 4.96 kHz.

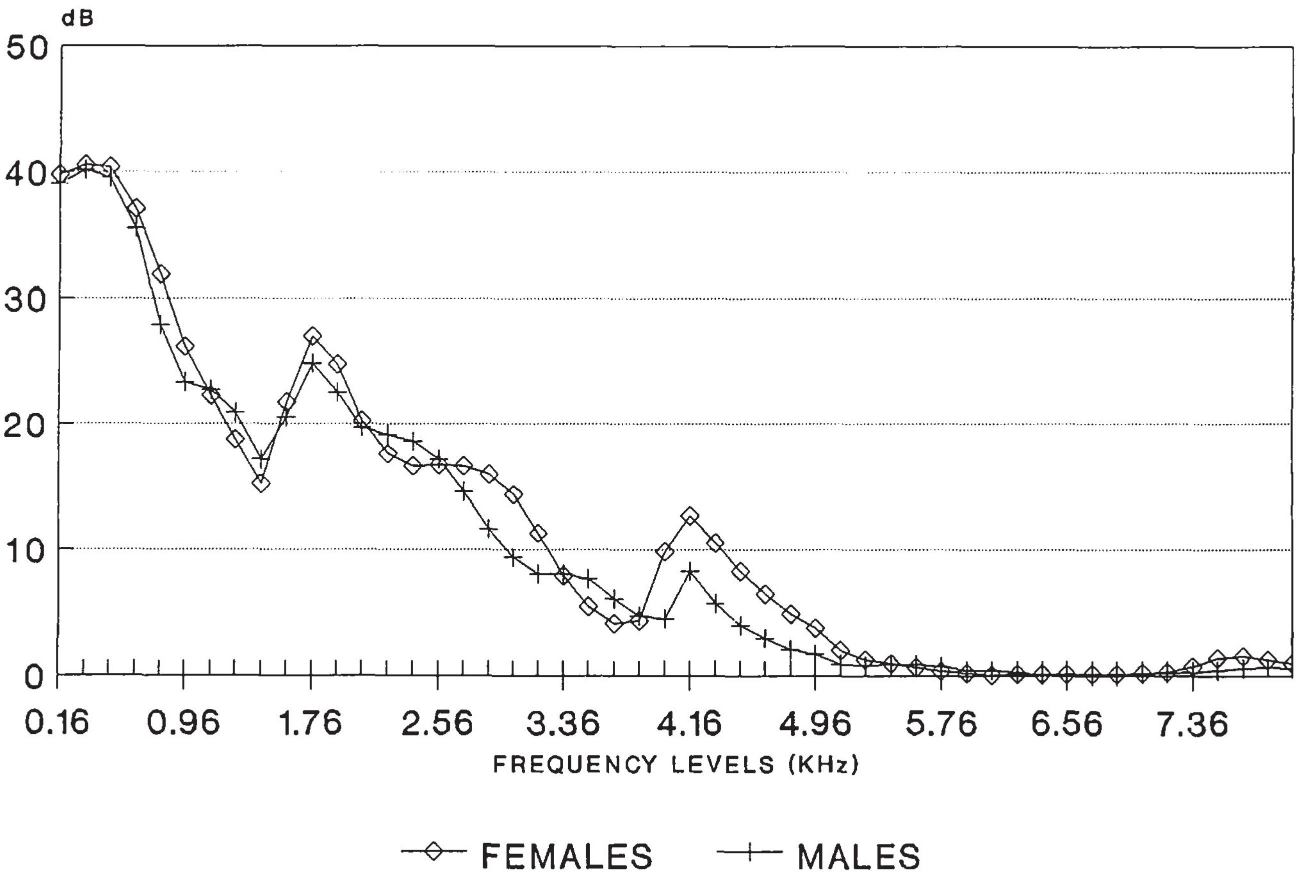

FIG. 1. Graphic representation of the mean values of amplitude (in decibels) corresponding to female and male voices in each frequency level analyzed (in kilohertz).

TABLE 1. *Results of analysis of variance for the mixed factorial design G × (L), being G the gender factor (men and women), manipulated between subject, and L the level frequency factor (50 levels), manipulated within subjects. The dependent variable is the amplitude in decibels*

Source	Sum of squares	Degrees of freedom	Mean square	F
Gender (G)	584.547	1	584.547	6.678[a]
Error	4,638.928	53	48.135	
Level (L)	381,473.979	49	7,785.183	1509.978[b]
Level × Gender	2,358.630	49	48.135	9.336[b]
Error	13,389.684	2,597	5.156	

[a] $p = 0.013$. [b] $p < 0.001$.

Later a discriminant analysis using amplitude as the criterion factor and the frequency levels as the prediction factor was conducted to assess if all the frequency levels were equally important in the differentiation of voices across gender. The results of this analysis are presented in Table 2. As seen, the frequency levels included in the gender discrimination equation for those acoustic factors are 0.96, 1.44, 1.92, 3.04, 3.20, 3.36, and 8 kHz. The classification of subjects in this study through the discriminant function was found to be 100%.

To evaluate the question of whether or not female voices presented greater levels of aspiration noise in the spectral regions corresponding to the third formant and a lower spectral tilt than male voices, as Klatt and Klatt (9) suggested, the energy concentration at the level of the third formant and the overall tilt of the spectrum source were analyzed. The amplitude of the frequency points had previously been examined, showing significantly higher values for female voices. In analyzing the overall tilt of the spectral source, the ratio of energy between 0–1 kHz and 1–5 kHz was calculated, as suggested by Löfqvist and Manderson (18). The results indicated that this ratio is greater among male speakers (mean = 5.215; SD = 1.286) than among females (mean = 4.565; SD = 0.731). These differences are statistically significant [$F(1,53) = 5.600$; $p < 0.022$].

TABLE 2. *Discriminate analysis utilizing amplitude as the criterion factor and the frequency levels as the predictable factor*

Variable	F to enter remove	U statistic	Approximate F statistic	Degrees of freedom
F096	7.326	0.1468	56.958	5.49
F144	7.156	0.1613	50.942	5.49
F192	4.031	0.1849	55.103	4.50
F304	44.916	0.5413	44.916	1.53
F320	5.321	0.1105	54.024	7.47
F336	4.567	0.1214	48.610	7.47
F800	4.949	0.1332	52.081	6.48

Classification Matrix

Group	Percent correct	No. of cases classified into group: Women	Men
Women	100.0	31	0
Men	100.0	0	24
Total	100.0	31	24

Jackknifed Classification

Group	Percent correct	No. of cases classified into group: Women	Men
Women	100.0	31	0
Men	100.0	0	24
Total	100.0	31	24

DISCUSSION

The results of this study showed that (a) significant differences were present between genders in the distribution of energy throughout the analyzed frequency values, taken from voice samples. This is reflected in the interaction effects of the gender and the frequency level factors found in the ANOVA. (b) Significant differences were not found in all of the spectrum's frequency levels, but rather were concentrated in the frequencies between 0.80 and 5 kHz, particularly in the frequencies 0.96, 1.44, 1.92, 3.04, 3.20, and 3.36 kHz. According to the results of the discriminant analysis, this is the spectral region that best differentiates the speaker's gender. (c) The spectra corresponding to women's voices showed a lower overall tilt; this was found on the ratio of 0–1/1–5 kHz. (d) The LTAS, as an average measure of continuous voice signals, is a useful instrument for detecting these sex-related differences and for determining the spectral regions where such differences are centered.

From the results of the discriminant analysis, it is seen that the frequency points of 0.96, 1.44, 1.92, 3.04, 3.20, 3.36, and 8.00 kHz are most important in voice quality differentiation. Within the abovementioned frequency points, those corresponding to 3.04, 3.20, and 3.36 kHz are located in the spectral regions near the third formant, and the higher values correspond to the female voices. The implications of these results agree with the proposal of Klatt and Klatt (9) that the acoustic characteristics of female voices lead to a "breathier" quality than in male voices. These authors, as indicated in the introduction, suggest that this quality can be explained by a longer opening and the presence of a posterior opening between the vocal folds, which would generate aspiration noise in the region of the third formant.

Klatt and Klatt (9) locate another consequence of these physioanatomical characteristics in the lower spectral tilt, because of the greater concentration of aspiration noise in higher frequencies. Löfqvist and Mandersson (18) indicate a way of quantifying the general spectral tilt via LTAS. They determined the energy drop in the spectra of hyperfunctional voices by the ratio 0–1/1–5 kHz. The present study has confirmed the differences between male and female voices to be in this ratio. As the lower values were registered in the female voices, a slower general tilt was seen in this group. However, as seen in Fig. 1, the spectral tilt in women's voices is greater by >1.60 kHz. This means that the general lowering of the spectral tilt (until 5.0 KHz) is due to a greater concentration of energy in the higher frequencies (1.60–5.0 KHz), according to Klatt and Klatt (9). These results suggest that the spectral tilt ratio should locate the cut-off point between high and low frequencies at 1.60 kHz (0–1.60/1.60–5.0) instead of at 1 kHz, as proposed by Löfqvist and Manderson (18). We believe that the different cutoff point put forth by the latter authors is due to their having attempted to distinguish between hyper- and hypofunctional voices, whereas this study's subjects presented with no vocal pathology.

An ANOVA was conducted with this new cutoff point, 1.60 KHz, to see whether this value could establish clearer differences between male and female voices. As such, the statistical significance increased $= [F(1,53) = 9.023; p < 0.004]$.

According to the discriminant analysis, another frequency point, 8.0 kHz, exists that indicates differences between the speaker groups. In all likelihood, another procedure of acoustical analysis is necessary to further investigate this question.

The existence of noisy energy in frequencies >8.0 kHz has already been studied. Shoji et al. (27) studied the energy present in frequencies >8.0 kHz in vowel emission by normal subjects. These authors detected significant differences in the energy distribution between vowels /a/ and /u/. Following a methodology similar to that of Shoji et al., we discovered differences in the configuration of the spectral energy in the regions ranging from 6–10 kHz and 10–16 kHz between vowels, and between dysphonic and nondysphonic speakers (28). We believe that the differentiation established by the discriminant analysis at the frequency point 8.0 kHz should move in this direction. Nevertheless, as LTAS requires a great amount of memory when dealing with long speech segments, our currently available equipment does not allow the study of the spectral zone >8.0 kHz using LTAS.

Our results agree with those of Klatt and Klatt (9) regarding the presence of greater aspiration noise in the region of the third formant in the female voice, noise that causes, according to these authors, the female voice to present a "breathier" quality than the male voice. This quality may be possibly due to learning/imitation of models and perhaps restricted to American women. The existence of similar effects in the results of analysis of the speech of Spanish women indicate that this characteristic may not be restricted exclusively to one female nationality subject group. It would be necessary to study this particular aspect in various other subject groups before generalizing this finding.

The differences in the methodological procedures in this study and in previous studies make it difficult to compare results. The materials that have served as stimuli in the acoustical differentiation of the speaker's sex have consisted of syllables (29), sustained vowels (30), and vowels in syllabic contexts, as well as prolonged voiced and unvoiced fricatives (2,20). The VTR parameters used most frequently in these studies have been the frequency, amplitude, and bandwidth of the first four formants. However, using a long-term averaged spectrum, such as LTAS, one cannot affirm that the points of greater amplitude that appear along this spectrum correspond to formant values as they are relative to specific sounds. In addition, the procedures employed in the earlier studies differ from those of the present study: electroglottography, inverse filtering, spectral analysis, and linear predictive coding (LPC) analysis prevail in the literature, whereas, this study used the LTAS. Nevertheless, despite the procedural and analytical differences between previous studies and the present research, the results of this study coincide with those found by other authors, and in our case with speech samples that were natural and independent of phonetic content.

With the data obtained in this study, we intended to identify the acoustical physiological relations in the human voice. The existing body of knowledge on LTAS does not permit the identification of these relations nor does it necessarily have to be the final goal of acoustical investigation. Our intention has been to contribute a model with which to compare, using sufficient statistical evidence, the profile of the spectral energy's distribution in male and female voices averaged on a long-term basis. It was our intention to contribute significant evidence that would aid in improving the current systems of synthesis and recognition of women's voices.

The determination of a spectral area, corresponding approximately to the third formant, particularly sensitive to the differential establishment of male and female voice models, can be seen as one of the more important contributions of this study. According to the data, it is this area of the spectrum that presents a significantly different profile in both sexes and toward which more investigative efforts should be directed. Future research might use a perceptive validation instrument in looking at spectral representations for the two voice groups. This might include, for example, first masking or filtering out the spectral regions that are irrelevant in voice identification before having listeners decide whether a particular LTAS sample corresponds to a male or female voice.

To conclude, different profiles of energy distribution in the spectrum can be established for male and female voices, and these differences, apparently, are due to the presence of greater aspiration noise in the women's voices. This causes the female voice, in contrast to the male voice to present a "breathier" quality. Because of this, the spectral tilt in women's voices is smaller than that in men's voices. Finally, the LTAS is a technique that is sufficiently sensitive for detecting these differences.

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