Male and female speech: a study of mean f_0, f_0 range, phonation type and speech rate in Parisian French and American English speakers

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Abstract

Many studies have been conducted on acoustic differences between female and male speech. However, they have generally been led on speakers of only one language, and have focused on a single acoustic parameter. The present study is an acoustic analysis of dissyllabic words or pseudo-words produced by 10 Northeastern American English speakers (5 females, 5 males) and 10 Parisian French speakers (5 females, 5 males). Several prosodic parameters were measured: mean f_0, f_0 range, phonation type (through H1-H2 intensity differences) and words' duration. Significant cross-gender differences were obtained for each tested parameter. Moreover, cross-language variations were observed for f_0 range, and H1-H2 differences. These results suggest that cross-gender acoustic differences are partly language-dependent and could be socially constructed.

Index Terms: speech and gender, fundamental frequency, phonation type, speech rate, cross-gender acoustic differences, cross-language variations, Parisian French, American English.

1. Introduction

Numerous studies on acoustic differences between female and male speech have been conducted. Among the different acoustic parameters, mean fundamental frequency is commonly considered the major cross-gender difference. It would be around 120 Hz for men and 200 Hz for women [1] [2], hence a higher pitch in female speech. These values slightly vary through age [3] and are broadly lower for smokers [4]. Mean f_0 is also known to be a decisive clue in speaker's gender identification from speech [5] [6] [7].

Several authors have brought to light that vowel formants tend to be located at higher frequencies in female speakers [8] [9] [10] [11]. The scope of this cross-gender difference strongly varies from one study to another, from one formant to another, and seems to depend on vowel type. The spectral characteristics of consonants also differ as a function of speaker's gender [12] [13] [14]: once again, resonant frequencies tend to be higher in female speech.

Aside from mean f_0, other suprasegmental parameters could be gender-dependent. Some studies suggest that f_0 range would be larger for female speakers [1] [15]. Nonetheless, there is no strict consensus on this point [16]: the acoustic unit used to measure f_0 range appears to be determining. When calculated in hertz, f_0 range is almost unequivocally larger in female speech, but it is unclear whether this difference exists when it is calculated in semitones [17] [18]. This can be accounted for by human perception of pitch [16]: female speakers, who typically have a higher mean f_0 than males, have to use a larger raw range (i.e. in hertz) to reach the same perceived pitch variation (i.e. in semitones).

Phonation type also seems to depend on speaker's gender. Female voices are often considered more breathy (i.e. having a greater *glottal open quotient –GOQ*) than male voices [19] [20] [21]. Male voices, at least in American English speakers, are typically more creaky (i.e. having a very low GOQ) than female ones [22]. However, these results slightly vary from one study to another, and depend on the acoustic parameter used to estimate phonation type. Intensity difference between H1 and H2 could be the most reliable measurement [23], if used properly [24].

Potential male-female differences in speech rate have also been investigated. In a broad study led on 600 American English speakers, Byrd [25] found that mean utterance duration was 6.2 % lower in male speakers, thus indicating a faster speech rate than female speakers. Similar tendencies were found in more recent studies [26] [27]. However, several authors found no significant cross-gender differences on this parameter [28] [29].

Some of these cross-gender acoustic variations can mainly be accounted for by anatomical and physiological differences that arise during puberty. First of all, vocal folds become longer and thicker in male speakers [30], which would account for their lower mean f_0. A second relevant anatomical parameter is vocal tract length, which corresponds to the distance from the vocal folds to the lips: all things being equal, the longer the vocal tract, the lower resonant frequencies [31]. The average length of the adult male vocal tract is about 17 to 18 cm, while the average female vocal tract is 14.5 cm long [16]. It would explain, at least partially, why consonant noise and vowel formants frequencies are generally higher in female speakers.

Most of the previously mentioned studies were conducted on English speakers. Interesting facts arise when one considers other languages' data. For instance, a study reported that in Chinese Wu dialect, mean F0 was almost equivalent for male and female speakers [32]. Furthermore, if one compares various acoustic studies about vowel formant frequencies conducted on different languages [33, 34], one can notice that cross-gender differences vary from one language to another: for example, female-male differences are relatively small in Danish but appear to be much greater in Russian.

How to account for such cross-language differences? Physiological and anatomical cross-gender differences are very unlikely to explain then, and one must consider the possibility of socially constructed behaviors. Nonetheless, we have to take into account that the comparisons made by Johnson [33, 34] were based on several studies led by different authors, at different times and using different methods. Therefore, we must be very careful when interpreting such results, which need to be confirmed.

Given such facts, it seems relevant to conduct a cross-language study on acoustic differences between female and male speech. Moreover, we can notice that most studies in this field focus on a single acoustic parameter, although a multiparametric analysis would probably be much more productive. The present study is an acoustic analysis conducted jointly on Parisian French and Northeastern American English female and male speakers. It focuses on the

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following prosodic parameters: mean f_0, f_0 range, phonation type and speech rate. The general hypothesis is that cross-gender acoustic differences are partly language-dependent.

2. Material and method

2.1. Linguistic material

French and English linguistic material was required for this study. Dissyllabic words and pseudo-words were used, so that many phoneme combinations could be tested. Their selection was based on two main criteria: make the two corpora as similar as possible, and limit the number of combinations by choosing only the most relevant phonemes while holding the last CV sequence constant: /pi/ was chosen as it can appear in word final position in both languages. Twenty-seven (C)VCV words or pseudo-words were finally chosen for each language:

- /C (plosive) – V – p – i / combinations: /tipi/, /tapi/, /tupi/, /dipi/, /dapi/, /dupi/, /kipi/, /kapi/, /kupi/, /gipi/, /gapi/, /gupi/ for the French corpus, /ˈti:pi/ , /ˈtæpi/, /ˈtu:pi/, /ˈdi:pi/, /ˈdæpi/, /ˈdu:pi/, /ˈki:pi/, /ˈkæpi/, /ˈku:pi/, /ˈgi:pi/, /ˈgæpi/, /ˈgu:pi/ for the English corpus.
- /C (fricative) – V – p – i / combinations: /sipi/, /sapi/, /supi/, /zipi/, /zapi/, /zupi/, /ʃipi/, /ʃapi/, /ʃupi/, /ʒipi/, /ʒapi/, /ʒupi/ for the French corpus, /ˈsi:pi/, /ˈsæpi/, /ˈsu:pi/, /ˈzi:pi/, /ˈzæpi/, /ˈzu:pi/, /ˈʃi:pi/, /ˈʃæpi/, /ˈʃu:pi/, /ˈʒi:pi/, /ˈʒæpi/, /ˈʒu:pi/ for the English corpus.
- /V – p – i / combinations: /ipi/, /api/, /upi/ for the French corpus, /ˈi:pi/, /ˈæpi/, /ˈu:pi/ for the English corpus.

English words were read by American speakers while French words were read by French speakers. There is no phonological lexical stress in French [35], but within the frame sentence used for the recordings (see 2.3) French speakers naturally produced an emphatic stress on the first syllable of each experimental word.

2.2. Speakers

Twenty monolingual speakers were recorded. Ten of them were French native speakers (5 women, 5 men) and ten others were American English native speakers (5 women and 5 men). The 10 American speakers all came from the same northeastern area of the United States (Pennsylvania, Massachusetts, New York State, or southern Vermont). The 10 French speakers all came from Paris area (Ile-de-France). Speakers were aged from 20 to 40 (SD=6.5 years). Mean age was 28.2 for US speakers (29.4 for females, 27 for males) and 26.6 for French speakers (27.2 for females, 26 for males). All speakers were non-smokers and had reported no speech disorder. Each of them received a USB memory stick for their participation in the study and was informed that the data from the recordings would be treated with confidentiality.

2.3. Recording procedure

Recordings took place in a quiet room, using a digital recorder *Edirol R09-HR* by *Roland*. English speakers read the English corpus aloud and French speakers the French one. Words were presented to the participants in an orthographical transcription. In order to make prosodic parameters consistent, words were placed into a frame sentence: “He said ‘*WORD’* twice” for the English corpus and “Il a dit ‘*MOT’* deux fois” for the French one. Speakers were asked to say each sentence twice, at a normal speech rate.

2.4. Acoustic analysis

Data analysis was conducted with *Praat* software. After having extracted the words from the frame sentence, their duration (in milliseconds) and mean f_0 (in Hertz) were obtained by creating a Pitch file for each word, and performing *Get total duration* and *Get mean* commands. This operation was automated by a Praat script.

F_0 range is the difference between the highest and the lowest f_0 frequency reached within a given linguistic unit (here, a dissyllabic word). It was collected manually through the *Pitch info* window: these data were taken in hertz as well as in semitones, which is a much more adequate scale [16].

In order to estimate phonation type, intensity differences between H1 and H2 were measured. The relative strength of H1 is correlated with glottal open quotient (GOQ): the stronger H1 is, the higher the GOQ [19, 23]. Nevertheless, H1-H2 can only be measured on open vowels: F1 would otherwise distort the results [19]. Thus, vowel [a] for French speakers and vowel [æ] for English speakers were the only ones taken into account.

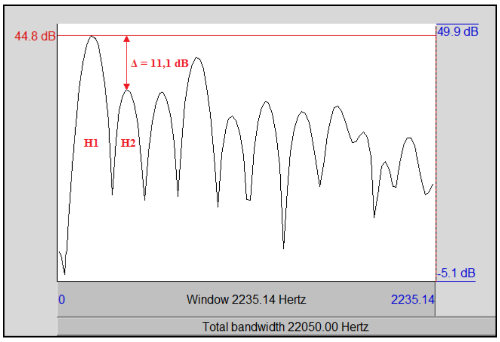

Figure 1. *Measurement of H1-H2 intensity differences on vowel [æ] extracted from word [æpi] produced by an American Female speaker.*

A 5 period selection was made on a central portion of each vowel. As shown in Figure 1, the corresponding spectrum was displayed and the difference between H1 and H2 intensity (in dB) was then calculated manually.

3. Results

3.1. Mean f_0

Mean f_0 (Hz) for French and American English speakers as a function of speaker’s gender is presented in Table 1, below.

Table 1. *Mean f_0 (Hz) measured on the 27 (C)VCV words for female (n=5) and male (n=5) French speakers and female (n=5) and male (n=5) American English speakers. Standard deviation among the 135 measurements (27 words * 5 speakers) is also mentioned for the four groups.*

	French Speakers		American speakers	
	Females	Males	Females	Males
Mean f_0 (Hz) - all words	**234**	**133**	**210**	**119**
SD	*18*	*12*	*27*	*19*

Unsurprisingly, mean f_0 appeared to be much higher for female speakers in both languages. The scope of this cross-gender difference is perfectly similar from one language to another: in both cases, females' mean f_0 is 76 % higher than males'. Moreover, we can notice that mean f_0 for both genders is slightly lower in American English speakers.

In order to test if these tendencies were significant, several statistical tests were conducted. First of all, a one factor ANOVA ("speaker's gender") was led on French speakers' data. The test revealed a very strong and significant effect of this factor: $F_{(1,268)}$=3064.26 ; p<.0001. A similar statistical test was performed on American English speakers' data. Once again, the speaker's gender appeared to have a very significant effect on mean f_0: $F_{(1,268)}$=1045.21 ; p<.0001. These results confirm that mean f0 was significantly higher for female speakers in both languages.

3.2. F_0 range

F_0 range for French and American English speakers as a function of speaker's gender is presented in Table 2. It was calculated both in Hertz and in semitones.

Table 2. *F_0 range (Hz and st) measured on the 27 (C)VCV words for female (n=5) and male (n=5) French speakers and female (n=5) and male (n=5) American English speakers. Standard deviation among the 135 measurements (27 words * 5 speakers) is also mentioned for the four groups.*

	French Speakers		**American speakers**	
	Females	**Males**	**Females**	**Males**
Mean f_0 range in Hertz - all words	**90**	**41**	**74**	**40**
SD	*22*	*11*	*19*	*15*
Mean f_0 range in semitones - all words	**6.76**	**5.35**	**5.87**	**5.95**
SD	*1.81*	*1.37*	*1.45*	*1.78*

When calculated in Hertz, f_0 range was much larger for female speakers in both languages. It was 120 % wider for females in French speakers, and 85 % wider for females in American English speakers. When the data are converted into semitones, a scale that shows the perceived pitch variation, the cross-gender difference completely disappears in American English speakers. On the other hand, f_0 range remains substantially higher for females in French speakers (+ 26 %).

One factor ANOVAs ("speaker's gender") were conducted on French speakers' data. When f_0 range was calculated in Hertz, a very strong and significant effect of this factor was found: $F_{(1,268)}$=549.19 ; p<.0001. When the data were given in semitones, the analysis also reveals a strong and significant effect of the speaker's gender: $F_{(1,268)}$=51.71 ; p<.0001. Therefore, in French speakers, mean f_0 range appeared to be significantly wider for females, even when it was expressed in semitones.

Similar statistical analyses were made on American English speakers' data. When f_0 range was expressed in Hertz, the test indicated a significant effect of speaker's gender: $F_{(1,268)}$=266.23 ; p<.0001. On the other hand, when the data were expressed in semitones, no significant effect of this factor was found: $F_{(1,268)}$=.14 ; p=.71. These results confirm that f_0 range was wider in female than in male American English speakers when expressed in hertz. However, contrary to French speakers, f_0 range was no longer wider in female speakers when it was converted into semitones.

3.3. Phonation type

Mean intensity difference (dB) between the first (H1) and the second harmonic (H2) for French and American English speakers as a function of speaker's gender is presented in Table 3. It was measured on open vowels, giving a total of 9 measurements for each speaker (9 words contained vowel [a] in the French corpus while 9 words contained vowel [æ] in the English corpus).

Table 3. *H1-H2 mean difference (dB) measured on the 9 open vowels of each corpus, for female (n=5) and male (n=5) French speakers and female (n=5) and male (n=5) American English speakers. Standard deviation among the 45 measurements (9 words * 5 speakers) is also mentioned for the four groups.*

	French Speakers		**American speakers**	
	Females	**Males**	**Females**	**Males**
Mean H1-H2 difference (dB) in open vowels	**3.8**	**-1.4**	**4.0**	**-2.9**
SD	*2.5*	*1.3*	*2.6*	*2.2*

H1-H2 intensity difference appeared to be greater in female speakers. It was true in both languages. This cross-gender difference reaches 5.2 dB in French speakers and 6.9 dB in American English speakers. This cross-language variation is mainly due to American English male speakers, who had a particularly weak H1.

A one factor ANOVA ("speaker's gender") was performed on French speakers' data. The analysis revealed a significant effect of this factor over H1-H2 intensity difference: $F_{(1,88)}$=157.22 ; p<.0001. The same statistical test was conducted on American English speakers' data. Similarly to French speakers, this test indicated that there was a significant effect of speaker's gender: $F_{(1,88)}$=180.04 ; p<.0001. These results confirmed that in both languages H1-H2 difference was higher in female speakers, which suggests that females' phonation type tends to be more breathy than males'.

In order to test if cross-language variations were significant, other statistical tests were conducted. Females' data from both languages were gathered and a one factor ANOVA ("speaker's language) was performed. The analysis showed no significant effect of this factor: $F_{(1,88)}$=.11 ; p=.74. A similar test was conducted on males' data. This time, a significant effect of speaker's language was found: $F_{(1,88)}$=13.55 ; p=.0004. This analysis confirmed that American male speakers had a significantly lower H1-H2 intensity difference than French male speakers, which suggests they used a creakier phonation type.

3.4. Speech rate

Mean word duration (ms) for French and American English speakers as a function of speaker's gender is presented in Table 4, below.

Table 4. *Mean word duration (ms) measured on the 27 (C)VCV words for female (n=5) and male (n=5) French speakers and female (n=5) and male (n=5) American English speakers. Standard deviation among the 135 measurements (27 words * 5 speakers) is also mentioned for the four groups.*

	French Speakers		American speakers	
	Females	**Males**	**Females**	**Males**
Mean word duration (ms)	**510**	**445**	**555**	**441**
SD	*90*	*58*	*77*	*54*

Results show that mean word duration was higher for female speakers in both languages. Cross-gender difference is wider in American English speakers (+26 %) than in French speakers (+15 %). This variation can be accounted for by the difference between French and American Female speakers: the words produced by the latter appeared to be longer than those produced by the former (+9 %).

A one factor ANOVA ("speaker's gender") was conducted on French speakers' data. This test indicated that there is a significant effect of this factor on words' mean duration: $F_{(1,268)}=48.94$; $p<.0001$. The same analysis conducted on American English speakers' data reveals a strong and significant effect of speaker's gender: $F_{(1,268)}=200.28$; $p<.0001$. These results confirm that speech rate was significantly higher for male speakers in both languages.

4. Discussion - conclusions

This cross-language acoustic analysis has given several remarkable results. Mean fundamental frequency, measured on dissyllabic words, was significantly higher for women in both languages, which broadly confirms results obtained in previous studies [1] [2]. Moreover, even though mean f_0 was slightly lower for both genders in American English speakers, the scope of the female-male difference was very similar in the two languages. This suggests that cross-gender differences in mean f_0 are relatively consistent across languages, apart from a few known exceptions, such as Chinese Wu dialect, in which male speakers tend to use an exceptionally high f_0 [32].

Regarding f_0 range, measurements have highlighted an interesting cross-language variation. When data were taken in hertz, f_0 range appeared to be significantly wider for female speakers in both languages, which supports results from previous studies [1] [15]. This cross-gender difference can be accounted for by the fact that female speakers, who generally have a higher mean f_0, have to use a larger f_0 range than males (in hertz) to achieve the same perceived result in terms of pitch variation.

Indeed, when f_0 range was calculated in semitones, a scale expressing perceived pitch variation, there was no more cross-gender difference in American English speakers. However, f_0 range was still significantly larger for French female speakers compared to their male counterparts. These results clearly support a former perceptual study from Pépiot [5] that showed a tendency for French listeners to associate flat f_0 with male voices, whereas no such effect was found in American English listeners.

H1-H2 intensity measurements in open vowels gave precious indications about speakers' phonation type. In both languages, significant cross-gender differences were found. H1's relative intensity appeared to be significantly greater in female than in male speakers, which suggests they tend to speak with a greater GOQ, hence a more breathy phonation type. Moreover, American English male speakers had a significantly lower H1-H2 than French male speakers, with strongly negative values. This indicates a very low GOQ, hence a creakier voice. Such results support the claim that female speakers' breathy voice quality would have a physiological origin [16], whereas male speakers' use of creaky voice would rather be socio-phonetic and language-dependant [22].

Concerning temporal measurements, dissyllabic words' global duration was found to be significantly greater for female speakers in both languages. These data are quite similar to former results obtained by Byrd [25] and Whiteside [27]. Cross-gender difference was slightly wider in American English speakers. Nonetheless, these results may suggest that the lower speech rate in female speakers, at least in a reading task, could be fairly consistent across languages.

Overall, the present study has brought to light several cross-gender differences, but also some cross-language variation between Parisian French speakers and Northeastern American English speakers. This tends to support the general hypothesis which claimed that cross-gender acoustic differences could be partly language-dependent. Furthermore, some of the female-male differences found in this acoustic analysis, such as differences in speech rate, are unlikely to be explained by anatomical and physiological factors. A large part of cross-gender variation is likely to be accounted for by gender social construction. Therefore, these data may be of interest for improving vocal rehabilitation of transgender people [36]. They could also be useful in speech recognition and automatic gender identification from speech.

Nevertheless, such results have to be interpreted with caution. Only 5 men and 5 women were recorded for each language. Despite the restrictive selection criteria and the small intra-gender variation, it seems quite difficult to generalize the results to the whole Parisian French and American English speaker populations. Furthermore, it is known that speech task influences several acoustic parameters, such as speech rate and phonation type [37]. These corpora were made of read dissyllabic words: it is unclear whether similar results would be obtained with spontaneous speech.

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