FUNDAMENTAL FREQUENCY CHARACTERISTICS OF MIDDLE AGED MEN AND WOMEN

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1. INTRODUCTION

In our project acoustic and perceptual differences between, and resemblances to, male and female voices are studied. When listening to male and female voices it appears that pitch is the most striking difference between the two. This difference is caused (mainly) by differences in the anatomical structures of the larynx and especially of the vocal cords of men and women. So, on the acoustic level we find a difference in fundamental frequency between male and female voices.

The vocal apparatus of pre-pubertal boys and girls is almost the same; this means that boys and girls can speak on the same fundamental frequencies and these frequencies can spread over the same range. Therefore, the voices of boys and girls are very much alike. During puberty the larynx of boys grows more rapidly and more extremely than that of girls, due to the inner secretion of sex hormones. Consequently, adolescent and adult male voices are considerably lower than female voices.

However, pitch is not the only difference between male and female voices. Timbre is another difference that is also determined by anatomical characteristics. The cavities of the vocal tract of men as a group are larger, mainly due to the fact that the larynx is situated somewhat lower in the neck and because the proportions within the vocal tracts of men and women differ (Fant, 1960). Therefore, the frequencies of the formants of male voices are lower than the frequencies of the formants of female voices, which causes a perceptual difference in timbre between the voices.

The fundamental frequency (pitch) characteristics of human voices have been measured in many studies. However, most studies have been limited exclusively to either male or female voices. As a result, it is often difficult to compare the data because the experimental conditions have not been the same or because the methods for fundamental frequency estimation were different. Moreover, knowledge about pitch behaviour in distinctive speech styles is rather scarce and the ranges along which the fundamental frequency varies are not fully known. In the present study speech samples from two speech styles of both male and female speakers have been collected. The aim was to find general characteristics in pitch behaviour in those two situations, whether these characteristics are sex-specific or not.

For what practical purposes could knowledge about fundamental frequency phenomena in male and female speech be of interest? Firstly, speech therapists can make good use of knowledge of pitch behaviour. When therapists have more insight into normal fundamental frequency characteristics, they would possess a measure by means of which they can get an objective insight into the progress of the patients during therapy. Also, trans-sexuals who visit speech therapists in order to arrive at the desired gender characteristics of male or female speech could take advantage of it.

Secondly, a better insight into the fundamental frequency phenomena of both sexes could be of great interest for the success of speech synthesis, speech recognition and

speaker identification. Aspects of fundamental frequency characteristics could be helpful in improving the quality (naturalness) of synthetic speech.
More or less related studies on the topic of fundamental frequency characteristics are quoted and discussed in the following paragraph. Subsequently, our own measurements on male and female fundamental frequency characteristics are presented and discussed. The results include mean values, the ranges of the frequency contours and a measure of variability.

2. FUNDAMENTAL FREQUENCY IN LITERATURE

2.1 Sex differentiation

It is often said that a male voice sounds about one octave lower than a female voice, although of course large individual differences can exist. The differences could be caused by factors like age, personality, situation and body size. As far as the factor of body size is concerned, Graddol and Swann (1983) performed an experiment on the relation between height, weight and fundamental frequency within a socially homogeneous speaker group (in order to avoid disturbing variables like cultural influences). Speaker height seemed to be reflected by the average fundamental frequency for the male sample, but for the female sample no relationship at all was found. Although this might suggest that the men were using their 'natural' voices and the women were distorting theirs, Graddol and Swann (1989) explained the results in another way. According to them, the men used the lower limits of their frequency range and adopted more monotonous intonation patterns than the women. The women varied more with respect to the use of their voices.
In the past, a number of experiments have been performed to establish the importance of the fundamental frequency in sex identification tasks. Schwartz and Rine (1968) showed that the sexes are distinguishable without information on the pitch by means of an experiment in which voiceless fricatives were presented to listeners. Nevertheless, the listeners were able to identify the sex of the speakers. Coleman (1971, 1976), on the other hand, performed some experiments in which speakers articulated on their natural voice source as well as on tones produced by a 'single frequency Electrolarynx' (with a fundamental frequency of 85Hz!). In these experiments too, listeners were asked to identify the sex of the speakers. The results suggest that in the absence of a natural glottal source the vocal tract resonance characteristics are the most important cue for sex identification. However, when the glottal source is present, the sex of the speakers would be perceived primarily by the fundamental frequency characteristics, whereas the vocal tract resonances would contribute only to a lesser extent.
Sachs (1975) reports of experiments in which listeners identified the sex of young children in several speech samples. Spoken sentences were presented to the listeners in a natural way as well as played backwardly. It was found that listeners responded (identified) less accurately when they heard the sentences backwardly. According to Sachs this means that in normal speech not only fundamental frequency level and resonance characteristics give information about the sex of the speaker. She suggests that prosodic cues like intonation and rhythm may also be important.
In line with Sachs' suggestions Fichtelius et al. (1980) found that rhythm and intonation would even be sufficient to identify a child's sex (although older children were classified better than younger children, because with age the speech becomes more prosodically differentiated). According to Fichtelius et al. (1980) boys speak faster than girls and girls make more variation in their intonation patterns than boys. In agreement

with this, Bennett and Weinberg (1979) report that monotonicity would give rise to higher male identification scores.
In her data on female impersonation Olsen (1981) found that the fundamental frequency of women varied within a frequency range of about two octaves while the men often limited their variability to one octave. Huber (1989b) stated that (two) female speakers made use of distinctly larger fundamental frequency variability compared to male speakers. However, in this study at least a large part of the larger variability is biased by the fact that the mean fundamental frequency of female voices is also about one octave higher. As a consequence, the range in fundamental frequency values in Hertz has to be larger to become perceptively the same, due to the logarithmic characteristics of the human ear. Huber also found that the area of low fundamental frequency values was lying distinctly below a 'normally distributed' fundamental frequency range for female speech, whereas this tendency was absent in the male frequency distributions. This suggests some use of laryngealization.
Huber segmented and classified the fundamental frequency tracings into intonation units using the 'continuous speech segment algorithm' (Huber, 1989a). By means of this algorithm it was found that the female speakers produced more intonation units than the male speakers, which would at least partly be caused by the tendency of female speakers, more than of male speakers to time align syntactic constituents with intonation units.
Van Bezooijen (1981) measured fundamental frequencies and ranges (in semitones) of male and female speakers while expressing a number of specific emotions. She found clear differences in frequency ranges between the distinctive emotions but no differences in range between the sexes.
Brend (1971) found differences in intonation contours between men and women. According to her (only perceptual?) observations, women make more incomplete long upsteps (a sudden movement from a relatively low frequency to a relatively high frequency). This would be perceived as a more 'polite' pattern than the men's equivalent, the use of small upsteps (an example Brend gives is the often used utterance: 'yes... yes... I know'). She also states that women make more high-to-low downglides (which would be a pattern for expressing unexpectedness or surprise) than men do.

2.2 Fundamental frequency and cultural rules

Many authors have suggested that sex differences which cannot be explained by physiological demands, are due to some sort of cultural 'rules'.
Sachs et al. (1973) argue that men and women modify their articulation in such a way that they reach those acoustic targets that correspond with the archetype of male and female voices. As a consequence females would raise their voices to a higher level than would be predictable from biological constraints and males would lower their voices. In the earlier mentioned experiments of Sachs (1975) some sort of indirect support is found for this view; listeners succeeded in identifying the sex of children's speech. So, even young children (six years old; matched for height) would have learned to change their voices towards the demands of their cultural environment.
In some other way Luchsinger and Arnold (1965) mention that cultural demands can modify physiological rules to a wide extent. They refer to two cultural groups in New York City, where 'Puerto Rican girls tend to speak on a rather high pitch', while '..many American women on the other hand find it desirable to speak on an artificially low pitch level' (p. 100). Some of these women are even visiting speech-therapists in order to lower their voices. Loveday (1981) found different fundamental frequencies in politeness formulae for Japanese as opposed to English speakers. Fundamental

frequency differences between Japanese men and women were clearly enlarged while English men and women both raised their frequency level to express politeness. Therefore, Loveday concludes that the function of pitch is different in these two cultures.

Apart from cultural influences the demands of an acceptable vocal image may be due to peer group pressure, family, mass media etc. (Cooper, as cited by Batstone and Tuomi, 1981). It also seems to be the case that voice quality is an important marker for someone's personality. The etymological origin of 'personality' is in the voice of the speaker; the Latin verb 'personare' literally means 'to sound through'. Henley (1977) argues that even slight deviations from the mean male and female fundamental frequency level have a clear influence on the impression of somebody's personality. According to Ohala (1983) some sort of 'frequency code' exists in human communication . Cross-culturally, high or rising pitches would mark questions, while low or falling pitches would represent statements. Moreover, he mentions that low pitch is related to 'big' as well as to 'assertive', while high pitch is connotated with 'little' as well as 'polite'. So, if male and female speakers change their voices according to this frequency code this might have the desired effect in a particular situation.

Ohala mentions that 'radio and television broadcast stations tend to hire announcers whose voice pitch is lower [...] so that they may sound authoritative and confident' (p. 9). Another example is the story about Margareth Thatcher. It tells that she took some speech therapy lessons in order to lower her voice, because she wanted to increase her authority (Henton, 1984).

From the above-mentioned studies it follows that people adjust their voices within certain limits, according to the targets they want to achieve whether fully conscious or not. It is evident that speaking on unsuitably high or low levels is disadvantageous for the voice, although it is uncertain what would be the optimum fundamental frequency levels for male and female voices. Linke (1973) reports of public-speaking text-books that 'advocate a relatively low pitch level as a desirable characteristic of effective performance' (p. 174). According to Linke this approach may have some detrimental effects, like a loss of expressiveness of the voice. He measured fundamental frequency levels, ranges and variability of young adult females from various speech classes. He found relatively low median frequency levels, compared with other data of female fundamental frequency levels. Moreover, less variability and a rather small frequency range were found in comparison with similar measurements on male voices.

3. PRESENT FUNDAMENTAL FREQUENCY MEASUREMENTS

3.1 Procedure

In our study recordings of speech fragments of ten male and ten female speakers of Dutch were collected. We did not want to exclude possible influences of SES (= Socio Economic Status) of speakers on pitch behaviour beforehand. Assuming that -in general- education level has a strong relation with SES we selected for both sexes five less educated and five highly educated speakers. All speakers were between 40 and 50 years of age. They did not show any speech deficiencies and their speech was non-dialectical. The speech material consisted of thirteen short Dutch sentences as well as of spontaneous speech samples. The sentences were the same for all speakers; the spontaneous speech material differed of course with respect to topic and length. These spontaneous speech samples were obtained next to earlier recordings in which the speakers had to perform several tasks, among which the reading of the sentences. The topics of the spontaneous speech samples ranged from the experimental situation and

the research aims to further thoughts or ideas of the subjects. The parts of the spontaneous speech samples that had been affected by interfering noises were left out.
In addition, a sustained /a:/ was recorded for fourteen of the twenty speakers. The instruction to the speakers was to produce a sustained /a:/ on their 'normal' voice level. Kuwabara and Ohgushi (1984) argue that the production of an open phoneme /a:/ will give the purest information about the anatomic structure of the speaker's voice; no speaker specific manners, dialect influences or linguistic background would obscure the results. We compared the fundamental frequency of the phoneme /a:/ of the distinctive speakers with the average fundamental frequency in the read sentences and the spontaneous speech samples.

The recordings were made in a sound treated booth with a Sennheiser microphone and a Revox A77 Tape recorder. Afterwards, all speech material was low-pass filtered at 4.5 kHz and digitised into a VAX 11/780 computer by means of a speech editing program at a sample frequency of 10 kHz. The material was analysed by means of a Linear Prediction based program (LVS-system by Vogten, 1983). Pitch detection was performed by the Subharmonic Summation method as described by Hermes (1988). Next, the incorrectly produced octave jumps (that were present in the male as well as in the female speech samples) were removed manually. In Figure 1 an illustration of this correction procedure is presented. In the top of the figure the original, uncorrected fundamental frequency contour of the Dutch sentence 'In mei zijn de bomen op hun mooist' (transl: The trees are most beautiful in May.) is shown as produced by one of the female speakers. In the middle the corrected contour, after removing the jumps is presented and at the bottom the sampled version of the speech waveform is given.

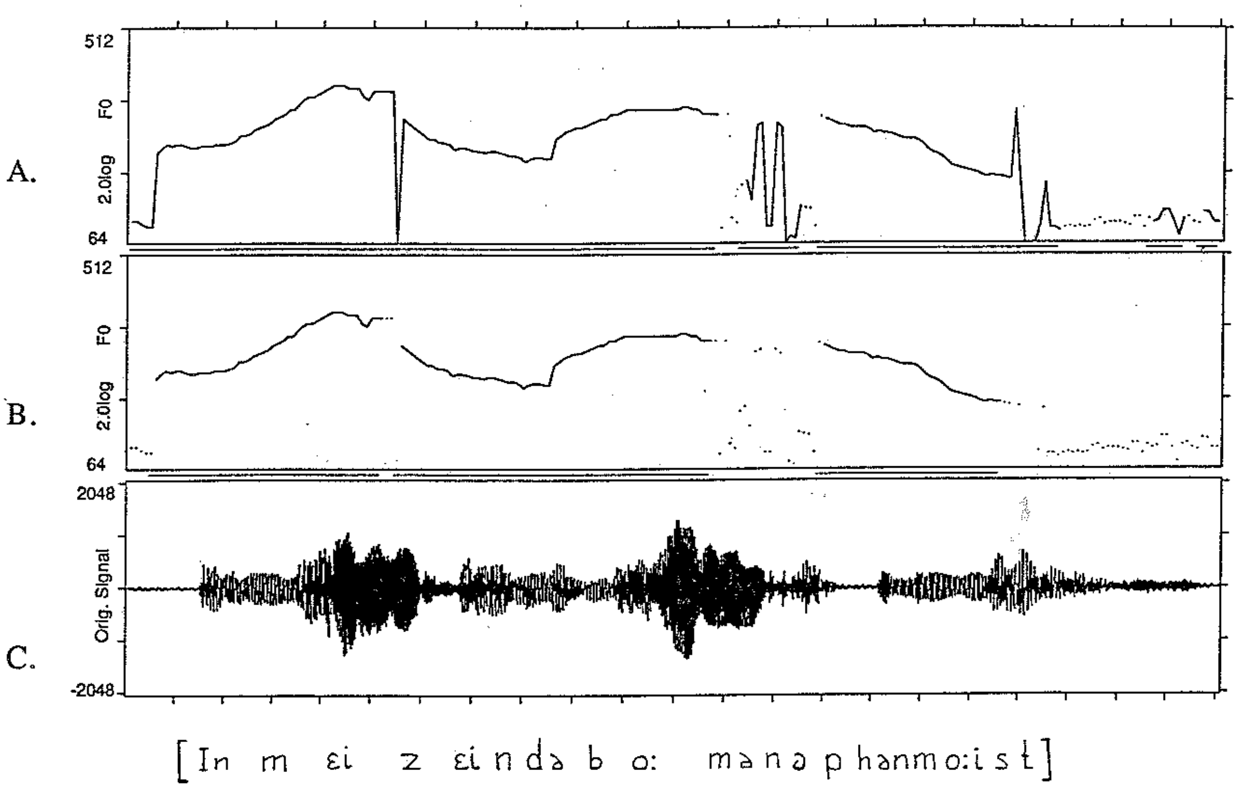


Figure 1. Fundamental frequency contour and waveform of a sentence as produced by a female speaker. A: original fundamental frequency contour; B: corrected fundamental frequency contour; C: original speech waveform.

From the resulting fundamental frequency contours the means, ranges and variability could be determined. It was decided to represent the fundamental frequency characteristics of the male and female voices on a logarithmic scale, because in this way it would be possible to compare the variations relatively to the fundamental frequency and to compare the acoustic findings from a perceptual point of view.

3.2 Results

3.2.1 Mean fundamental frequency

In order to determine the differences in fundamental frequency between the distinctive speakers the arithmetic means were measured for all speakers separately. Per speaker the mean fundamental frequency for all voiced speech samples is shown in Figure 2 (A for male speakers and B for female speakers). The means were determined for the spontaneous speech, the read speech and the sustained /a:/; they are represented as 12 ($^2\log$ (F0)) where F0 is the fundamental frequency in Hz. This means e.g. that an original value of 100Hz has been converted to a value of 79.73 and a value of 200Hz to 91.73. From 100Hz to 200Hz is one octave. In musical terms this means an interval of 12 semitones, which is the difference between the converted values.

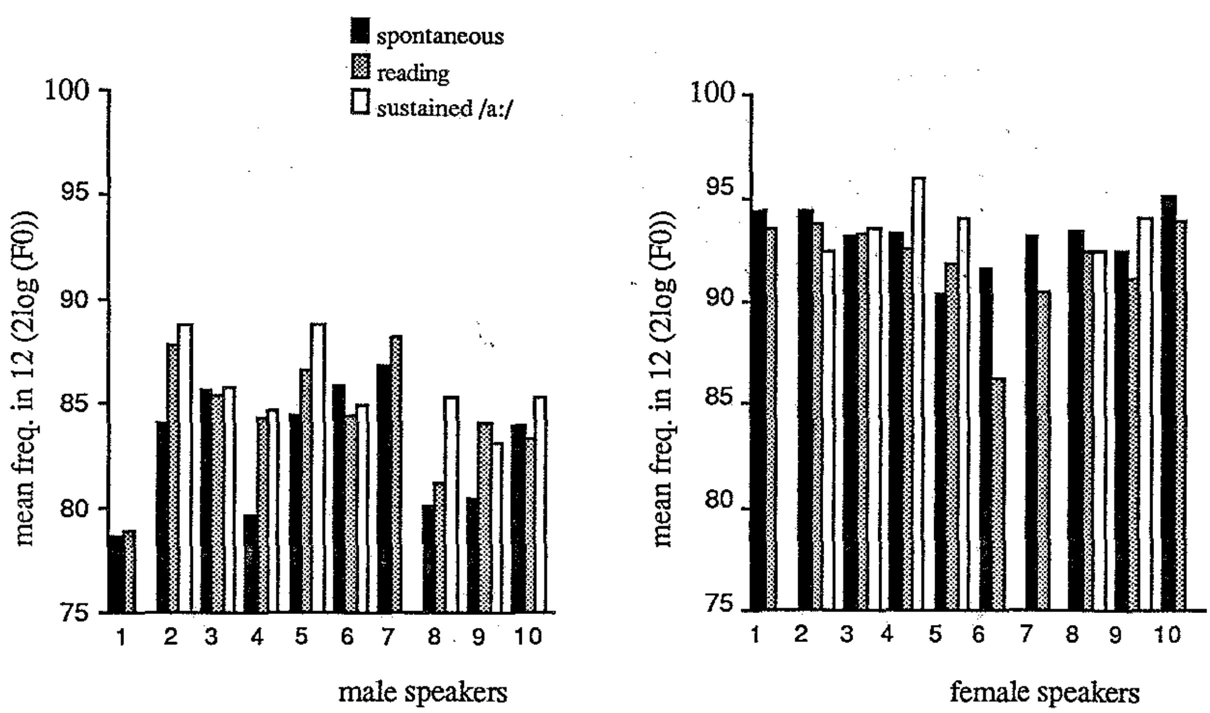


Figure 2. Mean fundamental frequency in 12 ($^2\log$(F0)) for sustained /a:/ and two speech styles for male and female speakers.

It is clear from this figure that there are distinctly different fundamental frequency regions for the male and female speakers. However, differences within the groups should not be underestimated either. The values for the men differ within a range of 8.5 semitones (between 95 and 155 Hz) and for the women within a range of 5 semitones (between 184 and 243 Hz). Furthermore, it can be seen that the female speakers tended to speak on a lower fundamental frequency in sentence reading performance (mean is 203 Hz) compared to the spontaneous speech performance (mean is 217 Hz).
For the male speakers this tendency was not found. For six male speakers the mean frequency level of the spontaneous speech was lower than of the read speech, while for two male speakers a small difference into the opposite direction was found. The other two speakers used practically the same mean fundamental frequencies in both speech styles.
The frequency level of the sustained /a:/ (as was available for six females and eight males) has been compared with the other mean values, which is also shown in Figure 2. If the fundamental frequency of an /a:/ would approximate the level of one of the speech styles, it would be possible to replace time consuming frequency measurements of larger speech samples with measurements of the sustained phoneme /a:/. However, it appears that for all but one of the speakers the fundamental frequency of the /a:/ is in between or above the mean values for the read sentences and for the spontaneous speech performance. The speakers with a relatively high /a:/ fundamental frequency (cf. male numbers 2 and 5, and female number 4) have probably tried to sing that /a:/. Also, the relative difference between the fundamental frequency level of the /a:/ and of the two speech styles varies along the speakers. Probably, too few data are available to draw strong conclusions from these results.

3.2.2 Relation between SES and fundamental frequency

In Figure 2 the male and female speakers with the numbers 1 to 5 represent the speakers with a lower SES and the numbers 6 to 10 represent the higher SES group.
The following results can be seen with respect to the question whether or not the fundamental frequency characteristics of the speakers with a different SES can be distinguished. For the female speakers lower mean frequency values were found in sentence reading compared to spontaneously speaking. This tendency has been caused mainly by data of the females with the higher SES (see also Table 1, where overall mean fundamental frequencies are presented in 12 ($^{2}\log(F0)$) as well as in Hz). On the average, the female speakers with a lower SES did not differ between the two speech styles.
It appeared that for the male speaker group, the speakers with the lower SES spoke on the average with a lower fundamental frequency in spontaneous speech in comparison with the higher SES group, but in the reading performance they increased to a slightly higher fundamental frequency than the speakers with the higher SES; the data of the higher SES group did not differ much between the two styles.

As can be seen from Table 1, the difference in means between male and female speakers is about 10 semitones in spontaneous speech and about 7 semitones in the sentence reading performance. This is in agreement with the already mentioned tendency that, on the average, the female speakers lowered their voices in the reading performance while the male speakers increased their fundamental frequency level.

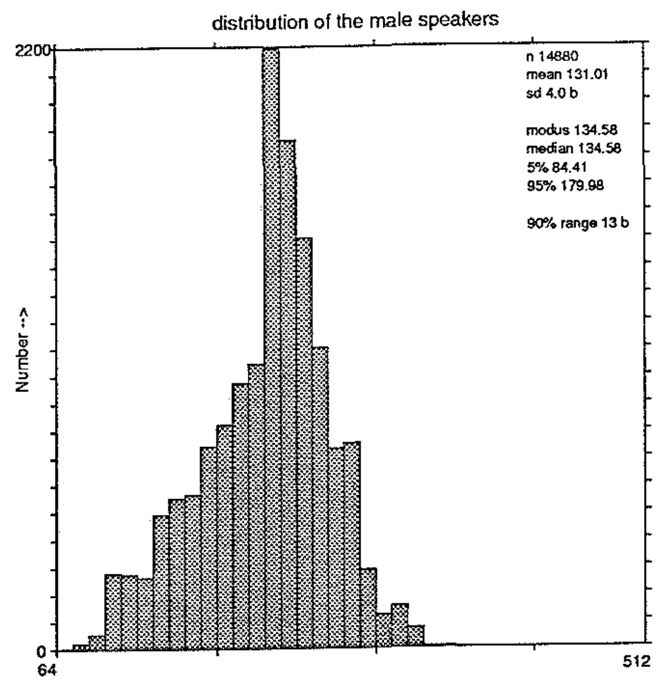
In the literature the median of the fundamental frequency is also an often used measure to indicate central tendency of the fundamental frequency, because it is not affected by very extreme scores. However, the above mentioned relations were also valid when the median values are compared.

Table 1. Mean fundamental frequency in Hz as well as in 12 (^{2}log(F0)), (= semitones) for two speech styles as measured for 5 males and females with a relatively high SES and 5 males and females with a relatively low SES.

		Spontaneous		Reading		sustained /a:/	
		Hz	12^{2}log	Hz	12^{2}log	Hz	12^{2}log
females	high SES	217	93	192	91	218	93
	low SES	217	93	214	93	228	94
	all	217	93	203	92	225	94
males	high SES	125	84	131	84	133	85
	low SES	119	83	134	85	153	87
	all	122	83	133	85	143	86

3.2.3 Distribution of the fundamental frequency

In Figure 3 the frequency distributions of the fundamental frequencies of the read sentences are presented for the ten male (A) and ten female (B) speakers. These distributions were determined by adding the data per sex from the read speech material. The horizontal axis represents a distribution in semitone intervals (so, 12 bars represent 1 octave). This axis is fixed on a maximum range of three octaves. The vertical axis represents the number of samples that fall within a certain interval. Together with the distribution the arithmetic mean, standard deviation in semitones, median, 90% range of occurring frequencies (in Hz as well as in semitones), and mode are given.
The ranges of the male and female distributions are almost the same. The 90% range is about 13 semitones for both sexes. This only means that the data from the two sexes differed not with respect to pitch range. While it can be seen that the distributions have been situated in distinctive areas in the frequency domain, it also might be seen that the overall shapes of the distributions are rather alike.



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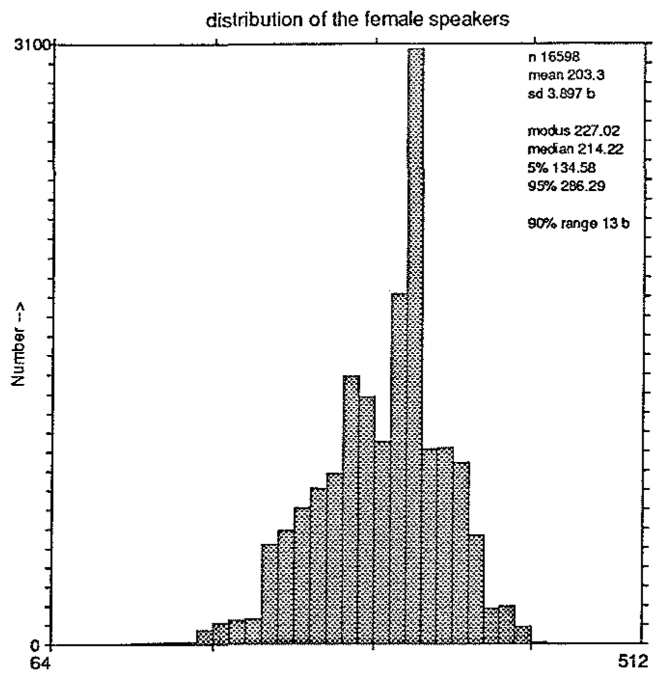


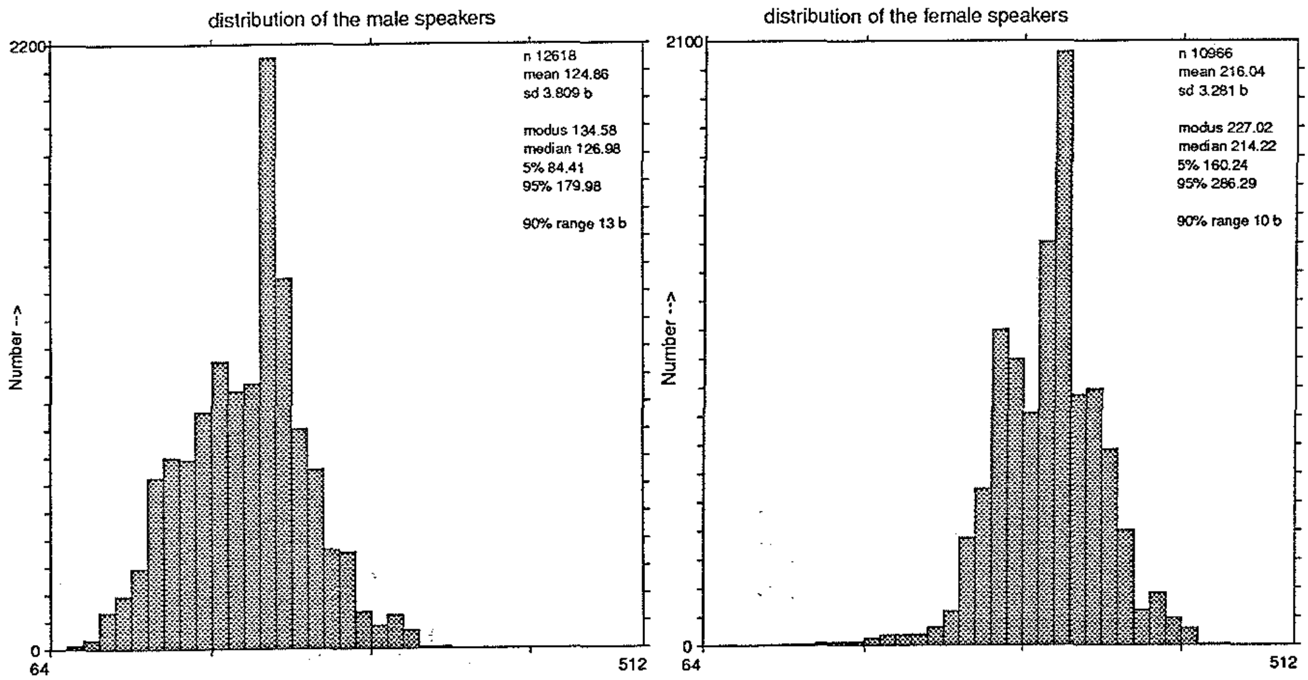
B

Figure 3. Fundamental frequency distribution in semitones for all male (A) and female (B) speakers in the sentence reading performance.

In Figure 4 the frequency distributions of the occurring fundamental frequencies in the spontaneous speech samples are presented for the male and female speakers, again in semitone intervals.

Again, these distributions differ with respect to global frequency region. But in contrast to the read sentences the fundamental frequency distributions of the male and female speakers are also different with respect to the frequency range. The 90% range occupies again 13 semitones for the male speakers, but only 10 semitones for the female speakers. This means that the fundamental frequency of the female speakers is within a range of less than an octave in their spontaneous speech. This does not necessarily mean that for each individual speaker the range of spontaneous speech was smaller than the range of read speech. In order to investigate those individual ranges, the distributions for the distinctive speakers had to be determined.

In our material it appeared that, on the average, the ranges of the spontaneous speech were slightly smaller than of the read speech for the individual speakers. For the read speech as well as for the spontaneous speech condition it appeared that no significant difference in range was found between the male and female speakers as determined by the Students t-test (independent subjects; t=0.668; df:18).



A B

Figure 4. Fundamental frequency distribution in semitones for all male (A) and female (B) speakers in the spontaneous speech performance.

3.2.4 Variability of the fundamental frequency

This far, a global insight in the appearing frequencies of all speakers has been presented. However, it is also interesting to study the variability of the fundamental frequency contour, which gives an impression of the perceived melodiousness. The range of the occurring frequencies alone is not a good measure for melodiousness, because it is possible that some speakers start at a relatively high fundamental frequency and decrease in a monotone way to the end of the utterance. This would probably be perceived as speaking monotonously, although the range of the occurring frequencies is rather large. Melodiousness implies that the pitch (fundamental frequency) is continuously varying around a baseline. We wanted to measure the fundamental frequency variability of male and female speakers in order to verify the suggestion from a number of studies, that female voices are more melodious than male voices.
Some sort of baseline has to be assumed through the speech samples, around which the rising and falling frequency movements could be measured.We decided to draw linear regression lines through the (voiced parts of the) fundamental frequency contours. Notions like declination were not taken into account. The standard deviation (Sd) from this regression line will give an indication of the variability of the fundamental frequency. As all speakers had produced the same sentences, this material was suitable

for comparison, whereas the spontaneous speech of the distinctive speakers was not. Therefore, the spontaneous speech has not been analysed in this way.
In Table 2 the mean variability expressed as standard deviation in semitones as measured for the male and female speakers is shown.

Table 2. Mean variability expressed as Standard deviation in semitones of male and female speakers per sentence.

Sentence	Male speakers	Female speakers
1	1.98	2.21
2	2.23	2.58
3	2.04	2.20
4	2.02	2.40
5	2.32	2.35
6	2.29	2.52
7	1.86	2.24
8	2.16	2.78
9	2.24	2.54
10	2.59	3.11
11	1.18	1.79
12	2.77	3.08
13	1.98	2.39
mean	2.13	2.48

From this table it is clear that the differences in Sd are not very large, but it can also be seen that for all cases the Sd (variability) of the female speakers is larger than that of the male speakers. A one-tailed t-test (matched subjects design) confirmed the tendency that the variability of the female speakers was larger ($t=7.404$; $df=12$; $\alpha=0.005$). The differences in variability between the successive sentences are relatively large.
Thus, although we found no clear differences between the sexes with respect to the overall distribution range of the occurring fundamental frequencies of the sentence reading speech, a consistent difference has been found in variability as determined by Sd around the regression line. When we divided the speakers into the two SES categories, it appeared that for the males as well as for the females the higher SES group tended to use on the average a larger variability as represented by Sd.

4. DISCUSSION

4.1 Mean fundamental frequency

In the literature on fundamental frequency characteristics one frequently finds the statement that the difference in fundamental frequency between the voices of males and females is one octave. However, it has to be kept in mind that most studies report of measurements on English speaking subjects.
Singh and Murry (1978) measured fundamental frequencies of ten male and female speakers (although the speakers were somewhat younger than the subjects in the present study) in text reading performance. For these American speakers, they found a mean

level of 220 Hz for the female speakers and of 115 Hz for the male speakers, which means a difference of 11 semitones or almost one octave between the sexes.
In the present study a distinctive frequency region as well as different mean frequencies were found for male and female speakers (about 125 Hz and 210 Hz respectively). However, the differences in mean frequencies were on the average significantly less than one octave. This difference depended on the speech style and was about 7 semitones in the read speech and 10 semitones in the spontaneous speech.
Huber (1989b) compared a few voice characteristics of two male and two female professional Swedish speakers. He found mean levels of 185 Hz for the female speakers and 95 Hz for the male speakers, which are somewhat lower levels than in our measurements.
In presenting or comparing frequency data it has to be kept in mind that there are a lot of variables that can have effected the results. However, although we had taken several variables like age, language and culture, and speech style into account, our data also showed rather large differences between the speakers within one group (Fig. 2). Other variables that could have been responsible for these differences are dimensions of the larynx, mental and physical condition, personality structure, using the pill, smoking etc. In spite of this we think that our data yield some interesting findings. For the female speakers we found a tendency that the voice is lowered in read speech compared to spontaneous speech, whereas for the male speakers no such tendency was found with respect to fundamental frequency level. Moreover, we found some differences in mean fundamental frequencies between the speakers with higher and lower SES. The lowering of the voice of the females with higher SES in sentence reading is in agreement with the suggestion of Linke (1973) that people are pushed to speak on a low level in order to achieve an effective reading performance. The fact that the mean fundamental frequencies for the two female groups are the same in the spontaneous speech suggests that the high SES group adapted their voice in the reading condition to the 'demands' of an effective reading performance.
On the average, the male speakers increased their fundamental frequency in the reading performance. The difference between the two SES groups is not clear from our data. The male speakers showed greater inter individual differences than the female speakers.

4.2 Range and variability

The distributions of the occurring fundamental frequencies for each speech style (Figs. 3 and 4) give some insight into the ranges that have been used by our male and female speakers in those speech performances. However, the presented distributions give the summed ranges of ten speakers, so the actual range is probably wider because all speakers of the same sex spoke within more or less different fundamental frequency regions and these interspeaker differences are also added in the distributions.
The suggestion found in some studies that female speakers would speak within a larger frequency range than males was not confirmed in the present study.
In the literature on the topic of intonation it is often stated that men speak with less variability in fundamental frequency than women (Huber, 1989b; Sachs et al., 1973; Olsen, 1981). However, Linke (1973) found results into the opposite direction.
We mentioned before that when variability measures are based on a linear frequency scale this finding is not very interesting, because it does not give a clear answer from a perceptual point of view. On the other hand, part of the literature on intonation or variability yields a complete lack of acoustic, quantitative measurements. We presented our acoustic data on a logarithmic scale in order to be able to compare the variability relatively to the fundamental frequency and to be able to interpret the results from a perceptual point of view. The most simple way to measure variability seemed to be by

means of linear regression lines. Lieberman et al. (1985) found support for this method. From their experiments they concluded that the all-points linear regression line was a better descriptor of the fundamental frequency contour than other measures like the subjectively 'visual abstraction procedure' or 'best fit' lines through the valleys or through the peaks.
We found a significant difference in variability between the male and female speakers in the read speech performance. However, the differences expressed by the standard deviations are not very large. More research has to be done evaluate these differences. Furthermore, it would also be interesting to study the intonation patterns rather than then the overall variability.

4.3 Conclusions

Although we admit that more measurements on more speakers have to be performed, we can already draw some conclusions from the present study:

--Spontaneous speech can possess other characteristics than speech that is read aloud.
--It is possible that speakers of different SES groups make use of distinctive frequency characteristics.
--Fundamental frequency differences between male and female speakers are not necessarily restricted to different fundamental frequency regions; in the present study we found also differences with respect to variability of the fundamental frequency and to behaviour in the two speech styles.

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REFERENCES

Batstone, S. and Tuomi, K. (1981). "Perceptual characteristics of female voices". Language and Speech 24, 111-123.

Bennett, S. and Weinberg, B. (1979). "Acoustic correlates of perceived sexual identity in preadolescent children's voices". J. of the Acoust. Soc. of Am. 66, 989-1000.

Bezooijen, R. van (1981). "Characteristics of vocal expressions of emotion: pitch level". Proc. Institute of Phonetics, Univ of Nijmegen 5, 1-18.

Brend, R. (1971). "Male-female intonation patterns in American English". Proc. of the 7th Inth. Congres of Phonetic Sciences, Mouton, The Hague, 866-869.

Coleman, R. O. (1971). "Male and female voice quality and its relationship to vowel formant frequencies". J. of Speech and Hearing Research 14, 565-577.

Coleman, R. O. (1976). "A comparison of the contributions of two voice quality characteristics to the perception of maleness and femaleness in the voice". J. of Speech and Hearing Research 19, 168-180.

Fant, G. (1960). Acoustic theory of speech production. Mouton, The Hague.

Fichtelius, A., Johannson, I. and Nordin, K. (1980). "Three investigations of sex-associated speech variation in day-school". in: Kramarae, C. (ed). The voices and words of women and men. Pergamon Press, Oxford, 219-225.

Graddol, D. and Swann, J. (1983). "Speaking fundamental frquency: some physical and social correlates". Language and Speech 26, 351-366.

Graddol, D. and Swann, J. (1989). Gender Voices. Basil Blackwell Ltd, Oxford, U.K.

Henley, N. (1977). Body politics: power, sex, and nonverbal communication. Prentice-Hall, Englewood Cliffs, New Yersey, 75-76.

Henton, C.G. (1984). "Normalization: fundamental problems". Paper presented at the Autumn Conference of the Institute of Acoustics.

Hermes, D.J. (1988). "Measurement of pitch by subharmonic summation". J. of the Acoust. Soc. of Am. 83, 257-264.

Huber, D. (1989a). "A statistical approach to the segmentation and broad classification of contiuous speech into phrase-sized information units". Proc. ICASSP-89, vol. 1, Glasgow, 600-603.

Huber, D. (1989b). "Voice characteristics of female speech and their representation in computer speech synthesis and recognition". Proc. Eurospeech '89, 477-480.

Kuwabara, H. and Ohgushi, K. (1984). "Experiments on voice qualities of vowels in males and females and correlation with acoustic features". Language and Speech 27, 135-145.

Lieberman, Ph., Katz, W., Jongman, A., Zimmerman, R. and Miller, M. (1985). "Measures of the sentence intonation of read and spontaneous speech in American English". J. Acoust. Soc of Am. 77, 649-657.

Linke, C.E. (1973). "A study of pitch characteristics of female voices and their relationship to vocal effectiveness". Folia Phoniatrica 25, 173-185.

Loveday, L. (1981). "Pitch, politeness and sexual role: an explanatory investigation into the pitch correlates of English and Japanese formulae". Language and Speech 24, 71-89.

Luchsinger, R. and Arnold, G. (1965). Voice-Speech-Language. Constable&Co Ltd., London.

Ohala, J.J. (1983). "Cross-language use of pitch: an ethological view". Phonetica 40, 1-18.

Olsen, C.L. (1981). "Sex differences in English intonation observed in female impersonation". Toronto Papers of the Speech and Voice Society 2, 30-49.

Sachs, J. (1975). "Cues to the identification of sex in children's speech". in: Thorne, B. and Henley, N. (eds.). Language and Sex: difference and dominance. Newbury House Publ., Rowley, Mass., 152-171.

Sachs. J., Lieberman, Ph. and Erickson, D. (1973). "Anatomical and cultural dterminants of male and female speech". in: Shuy, R.W. and Fasold, R.W. (eds.). Language Atttitudes; current trends and prospects, 74-84.

Singh, S. and Murry, T. (1978). "Multidimensional classification of normal voice qualities". J. of the Acoust. Soc. of Am. 64, 81-87.

Schwartz, M. and Rine, H. (1968). "Identification of speakers' sex from isolated whispered vowels". J. of the Acoust. Soc. of Am. 44, 1736-1737.

Vogten, L. (1983). Analyse, zuinige codering en resynthese van spraakgeluid. Diss, Eindhoven.