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ABSTRACT

The characteristics of French nasal vowels in the case of various CVCV combinations are studied. A set of CVCV utterances was read by speakers (5 males and 5 females) and analyzed using predictive coding techniques. The consonant consisted of voiced stops, unvoiced stops, nasal consonants... while the vowel V was one of 4 nasal French vowels. Vowel acoustic features such as formants and bandwidth frequencies, intensity, fundamental frequency and duration are studied. Most of the results obtained are in accordance with the acoustic theory. Differences between nasal and nasalized French vowels seem significant and the French nasal vowel characteristics seem as stable as those of the oral vowels. Application to speech synthesis and recognition is discussed. (Author)

ACOUSTIC ASPECTS OF FRENCH NASAL VOWELS

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INTRODUCTION

A theoretical and experimental study of the four french nasal vowels is presented. These vowels are : [ɑ̃] as in "chant", [ɛ̃] as in "fin", [œ̃] as in "brin" and [ɔ̃] as in "bon". The behavior of poles and zeros of the transfer function of the vocal tract when it is coupled to the nasal tract is investigated. A computer simulated transmission line model of this coupled system is used. The analytical study of these four vowels is done first by a graphical method which consists of styding the reactances, as seen at the coupling point, of the pharynx and mouth, on the one hand, and the nasal cavity on the other hand. The principle of this method is already described by FANT [1] and FUJIMURA [2][3]. Secondly the overall transfer function of the coupled system is investigated for the four nasal vowels.

Otherwise, 36 CVCV utterances spoken by six different speakers were analysed using linear prediction techniques. The obtained results are in accordance with the theoretical analysis.

RESULTS OBTAINED BY SIMULATION

The reactance of the pharynx and mouth, X_{mp}, as seen from the coupling point is calculated using a transmission line model of the vocal tract coupled to the nasal tract. As an initial step, we assume that the nasal vowels [ɑ̃], [ɔ̃], [œ̃] and [ɛ̃], are produced by the same vocal configurations corresponding to the oral vowels [ɑ], [ɔ], [œ] and [ɛ] respectively, but with a high degree of coupling with the nasal cavity. The used area functions corresponding to the four french oral vowels were taken from BOË [4], while the nasal cavity dimensions are those used by HOUSE and STEVENS [5]. The driving point reactance of the nasal cavity, X_n, is calculated for four different degrees of coupling. Differences between the approximated area functions adopted and the real configurations refered to by DELATTRE [6] are being studied.

For each of the four french vowels, we calculated X_{mp} which is then plotted with the curves representing $-X_n$ for four different degrees of coupling. Slide [1] shows the case of the vowel [ɛ̃]. The coordinates for which X_{mp} is infinite corresponds to the formant frequencies F_1, F_2, F_3 of the corresponding oral vowel. When the nasal cavity is added, the intersection between X_{mp} and $-X_n$ gives the new oral formant frequencies F_1', F_2', F_3' and two nasal formants F_{1N}, F_{2N}. We notice that there are two nasal antiformants A_{1N} and A_{2N} where X_n is zero. In other words, the addition of the nasal cavity introduces two nasal pole-zero pairs in the considered frequency range.

As seen from slide [1], the first nasal formant F_{1N} is quite stable and depends to a large extent on nasal cavity characterictics. On the contrary, the first oral formant frequency F_1' varies a lot with changes in the oral or nasal characteristics and is higher than F_1 of the corresponding oral vowel. On the other hand, the second formant F_2' is practically the same as F_2 and is not sensitive to changes in the amount of nasal coupling or the nasal characteristics. For this nasal vowel, the effect of the second nasal pole and zero is expected not to be very important since the zero is in the vicinity of the pole. We can conclude that nasality distinctive features for the nasal vowel [ɛ̃] are to be found mainly in the first and third formant range and practically nothing in the 2nd formant range.

For the nasal vowel [ɑ̃], slide [2], the first nasal formant F_{1N} is stable, whereas the position of the first nasal zero A_{1N} and that of the first oral formant F_1' are sensitive to the degree of coupling. A_{1N} gets nearer to F_1' as the degree of coupling increases and, consequently, the amplitude of F_1' could be strongly weakened. The second oral formant frequency F_2' is practically the same as that of the corresponding oral vowel F_2 and does not vary with changes in the coupling degree or in nasal characteristics. F_3' is higher than F_3 and the role of the second nasal pole-zero pair is more important for this vowel than for the previous one. Moreover, the second nasal pole is sensitive to the degree of coupling whereas the corresponding zero is approximately fixed and is characteristic of the nasal cavity. This situation is the inverse of that presented by the first nasal pole-zero pair where the pole remains fixed and the zero varies with coupling. These results were verified to be valid for different configurations of the nasal cavity.

For the vowel [$\tilde{ɔ}$], slide [3], the second formant F_2 is low compared with the other vowels considered. Accordingly, with nasal coupling the first formant can disappears due to two effects : either a nasal antiformant A_{1N}, near F_1 or F_1' which joins F_2'. Consequently no detection of the first oral formant F_1' is expected in the case of this nasal vowel.

Finally, slide [4] shows the results obtained for the vowel [$\tilde{œ}$]. Here, the same situation as for the vowel [$\tilde{ε}$] is obtained with the exception that for the vowel [$\tilde{œ}$] the first nasal formant frequency F_{1N} could be higher than F_1 (because of the low value of F_1).

In summary, the following remarks can be stated concerning the four french nasal vowels studied :

1. a stable nasal formant F_{1N} and a stable nasal antiformant A_{2N} are obtained for a given nasal cavity and different degrees of coupling. These two features are speaker characteristics.
2. the oral first formant frequency F_1' is higher than F_1 ; this formant is unstable and could disappear as in the case of the vowel [$\tilde{ɔ}$].
3. a nasal antiformant A_{1N} located between F_{1N} and F_1' is obtained. This nasal zero approaches F_1' as the coupling degree increases and, consequently, the amplitude of the first oral formant of nasal vowels is expected to be weak.
4. the oral second formant F_2' is very near F_2 but its amplitude could be different.
5. the oral third formant F_3' is higher than F_3 and depends on the degree of coupling. This dependance is less important than in the case of the oral first formant F_1'.
6. the role of the second nasal pole-zero pair is more important for the back nasal vowels [$\tilde{a}$] and [$\tilde{ɔ}$], than for the front nasal vowels [$\tilde{ε}$] and [$\tilde{œ}$].

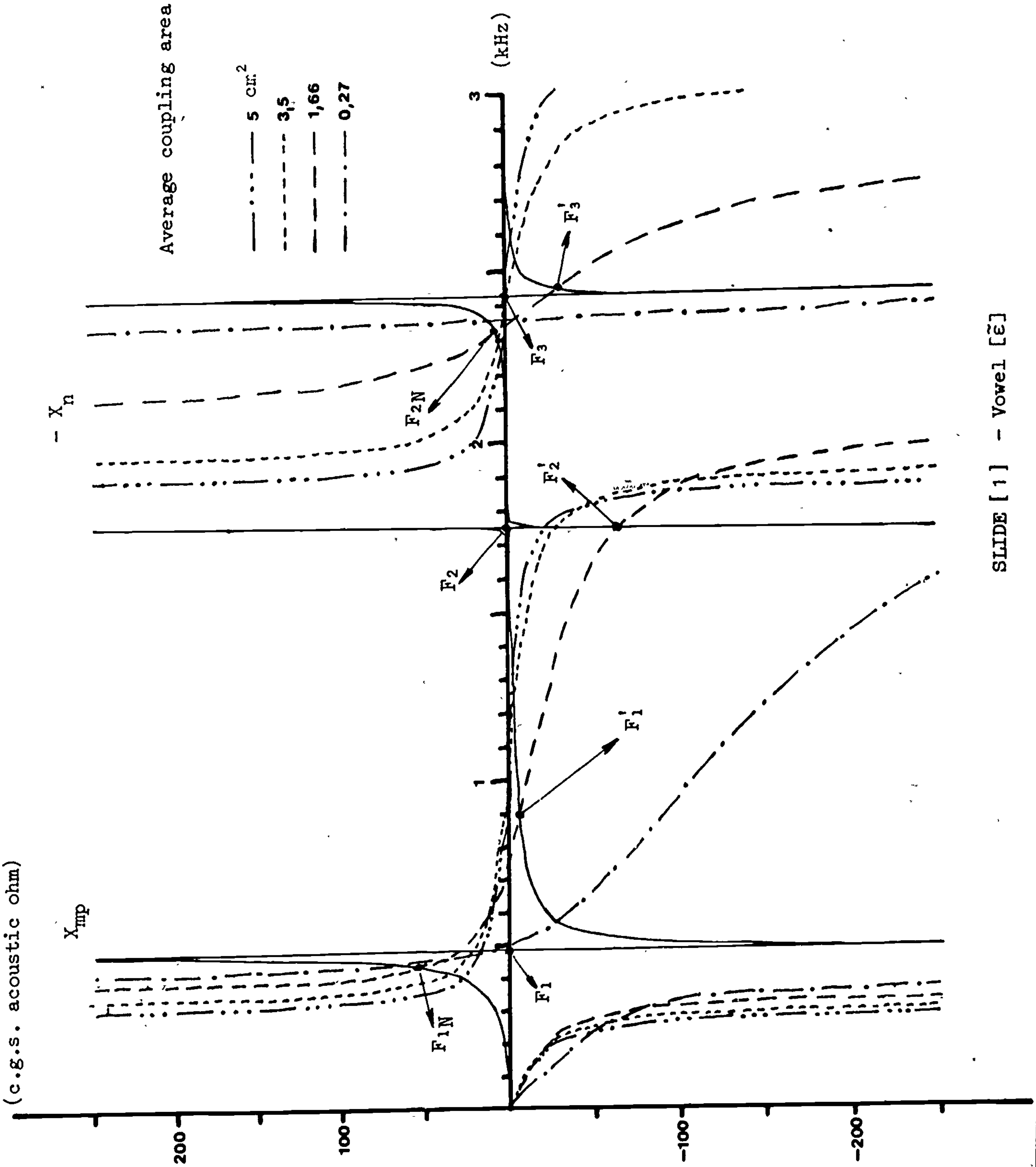
To study the behavior of poles and zeros of the coupled system from the spectral point of view, the transfer function of the four nasal vowels were calculated for different degrees of coupling (the radiation at the mouth and nostrils were taken into account). Slide [5] shows the result for the vowel [$\tilde{a}$].

The only losses included are those due to the radiation impedances and to viscosity. The degree of coupling is determined by the first two sections. The combined output has a well defined first nasal pole and zero. When compared to the calculated spectrum of the corresponding oral vowel, we find that in addition to the nasal pole-zero pair, there is an upwards shift of the first and third oral formants from 620 Hz to 810 Hz and from 2090 Hz to 2140 Hz respectively. The second oral formant remained unchanged. The presence of the second nasal pole-zero pair is not well defined.

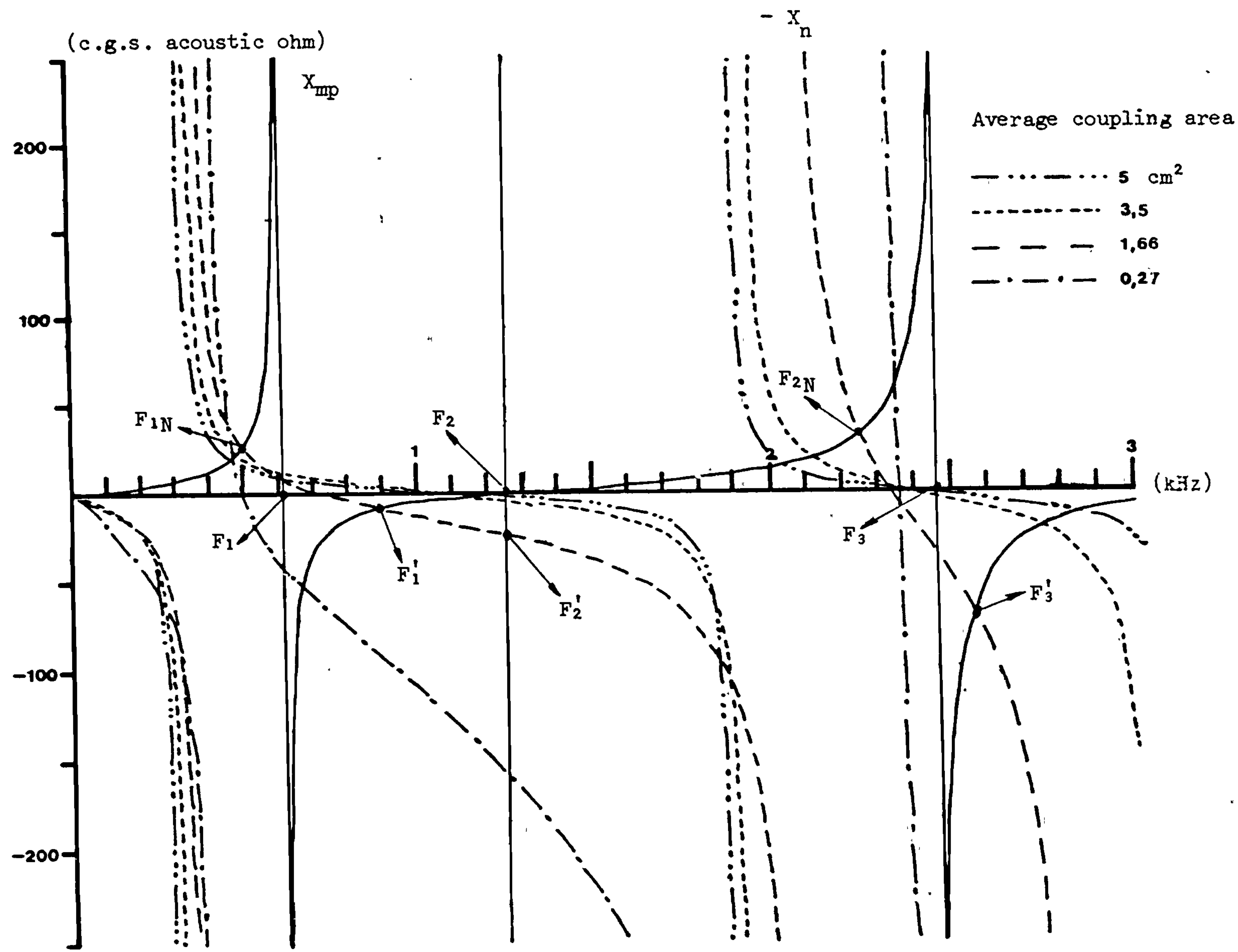
ANALYSIS OF NATURAL FRENCH VOWELS - RESULTS AND DISCUSSION

Using linear prediction techniques [7], 36 CVCV combinations were analysed. The consonant "c" consisted of voiced stops [b] [d] [g], unvoiced stops [p] [t] [k] and nasal consonants [m] [n] [ɲ] ; while the vowel "v" was one of the four french nasal vowels [ã] [ɔ̃] [œ̃] [ɛ̃]. The analysis was done for six speakers : five males and one female. The middle of the first vowel of each of the 36 utterances was analysed. The formant frequencies and bandwiths as well as the fundamental frequency were computed. The duration of the first vowel is also mesured. For comparison purposes, the same parameters were calculated for the four corresponding oral vowels for one male speaker.

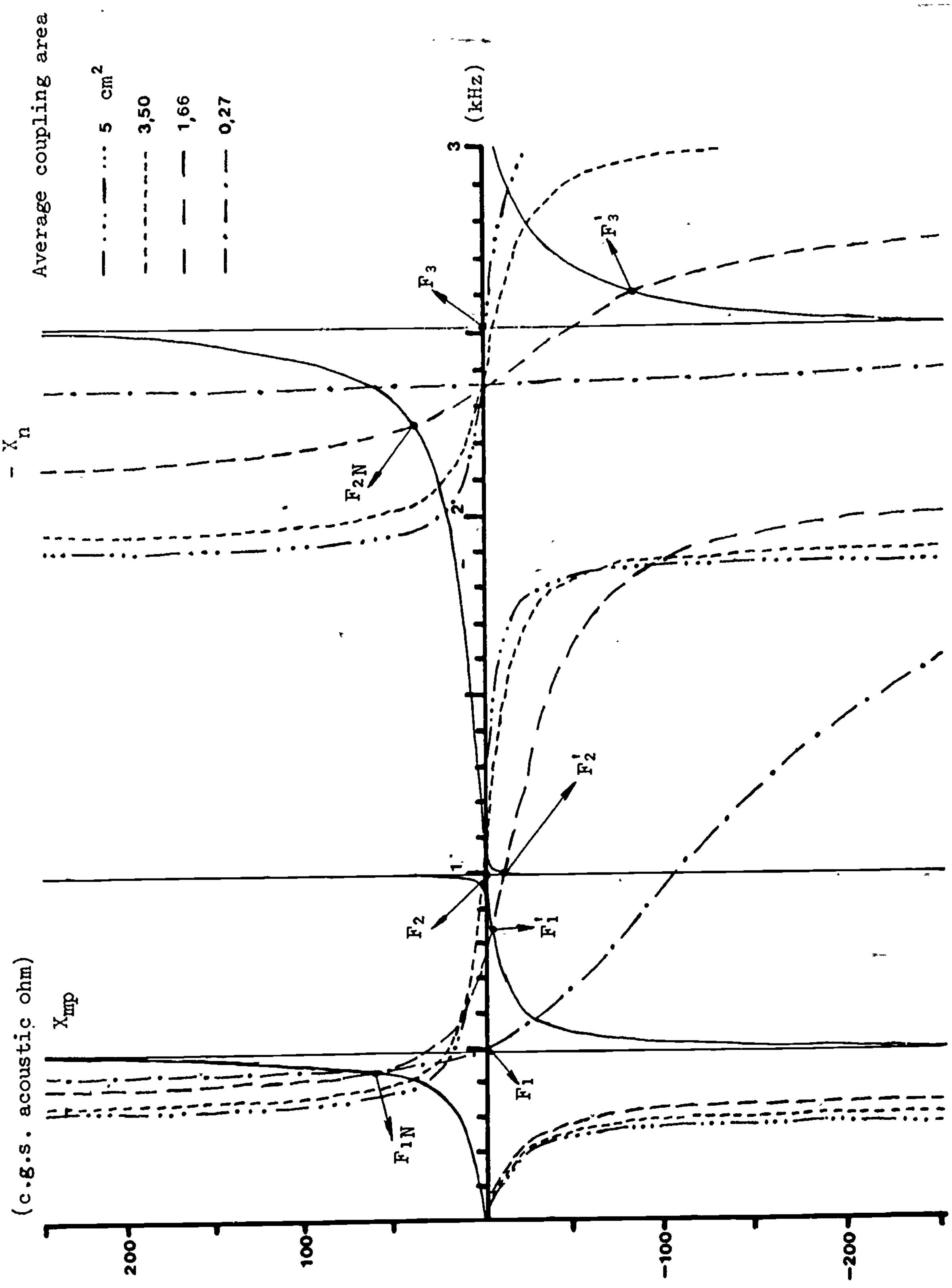
Slide [6] gives the average over five male speakers of the results obtained for each nasal vowel classified with respect to consonantic context. The first three oral formants and the first nasal formant with their corresponding bandwidths are indicated. The standared deviation for each case is given between parenthesis. From there data, the following remarks can be stated :



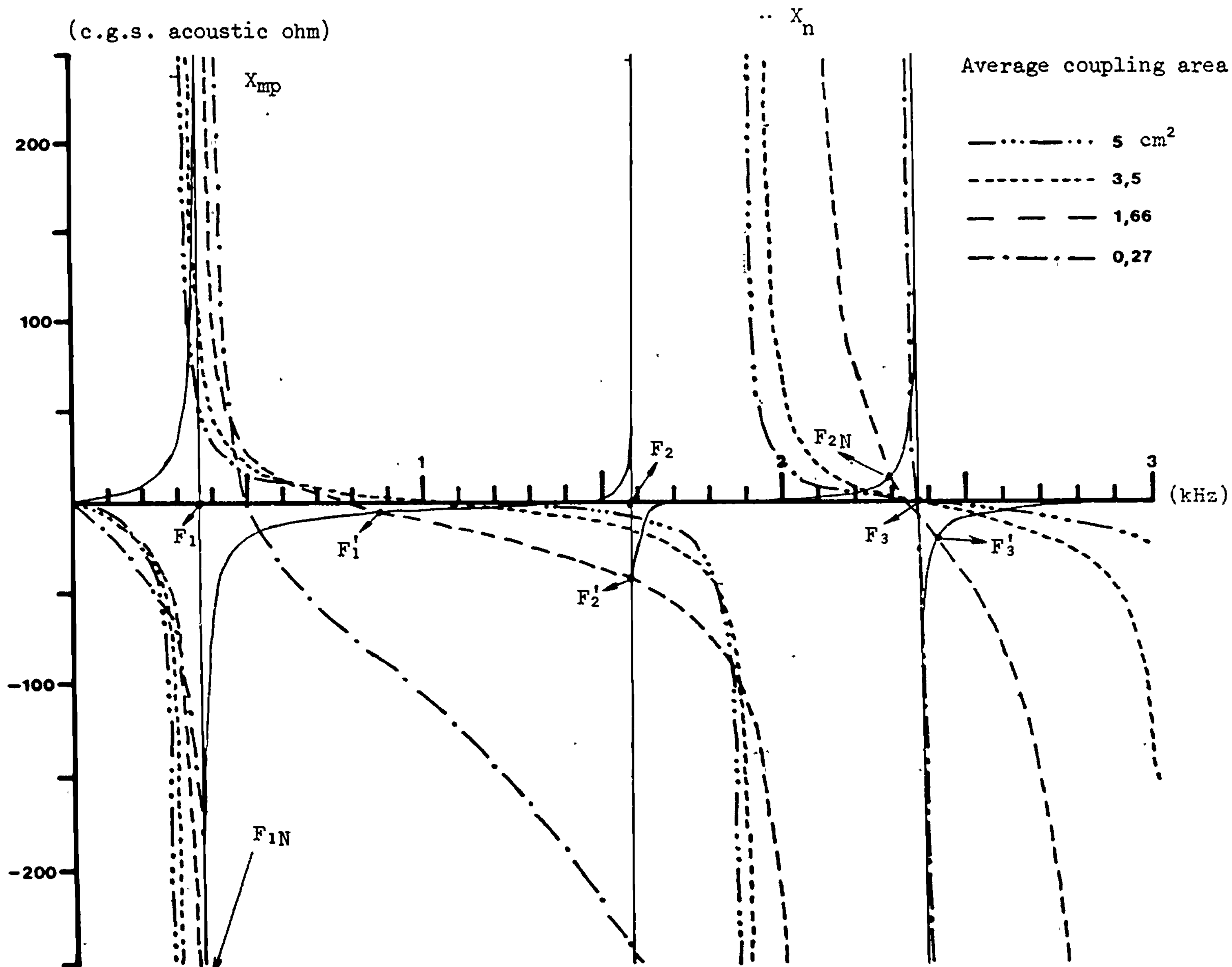
SLIDE [1] - Vowel [ε̃]



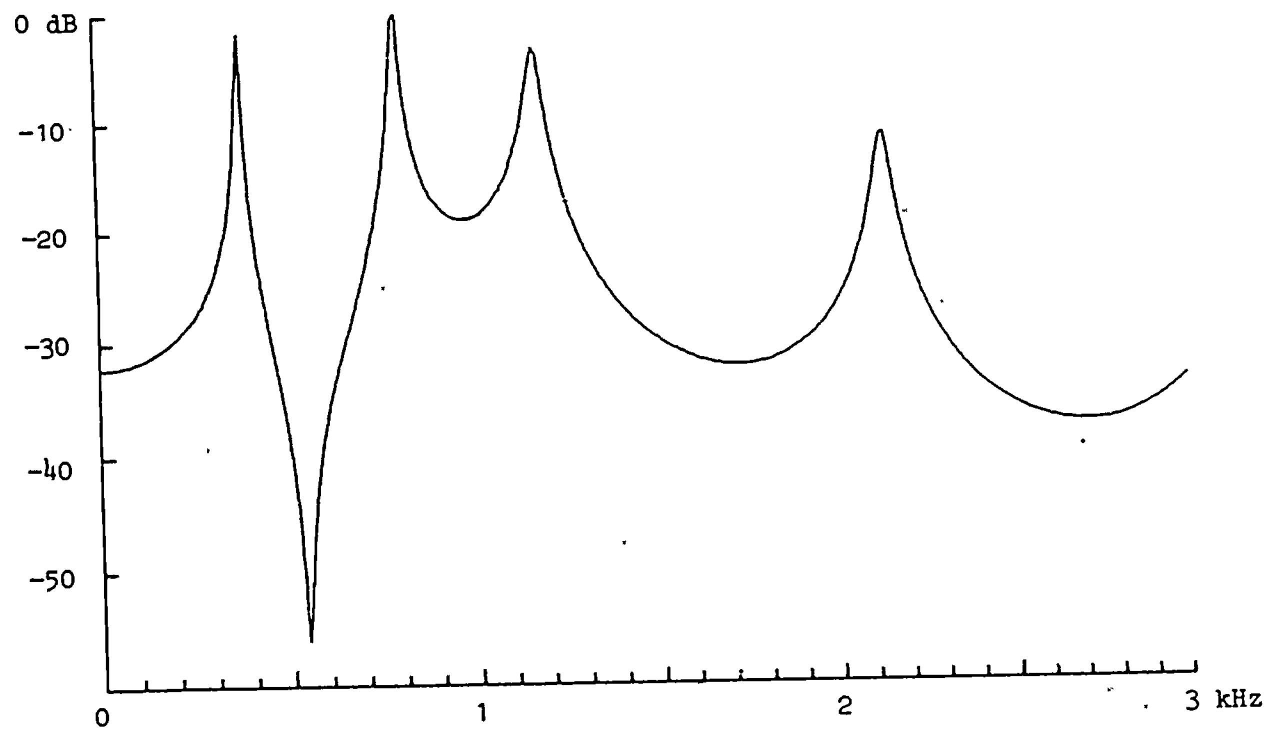
SLIDE [2] - Vowel [ã]



SLIDE [3] - Vowel [ɔ̃]



SLIDE [4] - Vowel [œ̃]



SLIDE [5] - Calculated spectrum of the vowel [ã]

SLIDE [6] - Formants and bandwidths of nasal vowels averaged over five male speakers.

		F'_1	B'_1	F'_2	B'_2	F'_3	B'_3	F_{1N}	B_{1N}
ɛ̃	(b,d,g)	735(74)	218(69)	1663(156)	148(62)	3155(351)	217(116)	409(137)	117(47)
	(p,t,k)	718(190)	272(116)	1649(140)	168(73)	3119(347)	212(86)	430(149)	135(73)
	(m,n,ɲ)	754(219)	255(89)	1697(225)	176(92)	3004(209)	255(91)	413(149)	124(46)
œ̃	(b,d,g)	656(164)	239(85)	1420(177)	146(70)	3069(287)	201(94)	400(126)	127(49)
	(p,t,k)	644(183)	282(102)	1388(148)	141(80)	3036(254)	273(118)	415(134)	145(77)
	(m,n,ɲ)	651(159)	224(83)	1448(170)	174(109)	2947(124)	196(97)	400(139)	124(54)
ɑ̃	(b,d,g)	619(143)	197(80)	1057(81)	137(51)	3274(240)	253(99)	381(125)	183(128)
	(p,t,k)	597(176)	181(57)	1039(78)	129(65)	3252(287)	279(91)	407(147)	144(106)
	(m,n,ɲ)	587(178)	186(71)	1055(128)	145(100)	3180(233)	251(102)	368(112)	128(109)
ɔ̃	(b,d,g)			764(133)	189(106)	3065(433)	286(118)	431(108)	135(37)
	(p,t,k)			711(107)	170(94)	3049(510)	268(85)	442(110)	159(89)
	(m,n,ɲ)			733(137)	195(96)	3040(487)	297(99)	419(122)	144(81)

1. There is a distinct nasal formant F_{1N} for all of the four nasal vowels which is around 400 Hz. The corresponding standard deviation is found to be large when averaged over the five speakers, nevertheless, it is quite low for each speaker alone. This means that the first nasal formant is a characteristic of a given speaker and mainly depends on the nasal-tract dimension.

2. The oral formants F_1', F_2', F_3' are always detected for these nasal vowels except for the first oral formant F_1' of the vowel [ɔ̃].

3. For some french speakers, there is an unstability in the pronunciation of the nasal velar consonant [ɲ] as in "signe". This is reflected in the high standard deviation of the oral formants corresponding to this case.

Slide [7] shows, for one speaker only, the obtained results for the four nasal vowels and their corresponding oral vowels. It is very interesting to notice the stability of the nasal formant for all the nasal vowels, while the first formant F_1' varies much more than F_1 of the corresponding natural oral vowels. This unstability of the first oral formant can be deduced from the higher standard deviation for the nasal vowels. It can also be deduced comparing changes in F_1' and F_1 from one consonantic context to another. These changes are more important for nasal vowels slide [8].

This phenomena is not noticeable in the case of the second formant (slide [9]) whereas for the thirs formant it exists but not as prominent as for the first formant.

A plot of the bandwidths B_1' of the first oral formant for the nasal vowels in comparison with those of the corresponding oral vowels (slide [10]), shows that a wider bandwidth is a characteristic feature of nasal vowels. This aspect can be used in nasal vowel recognition.

On the last slide [11], we have shown for one female speaker and one male speaker the averages and standard deviations of the nasal and oral formants for each of the four nasal vowels. We notice that the remarks already stated are also valid for the female speaker. The nasal formant is characteristic of the speaker and is approximately the same (with small standard deviation) for all four nasal vowels whether the speaker is male or female.

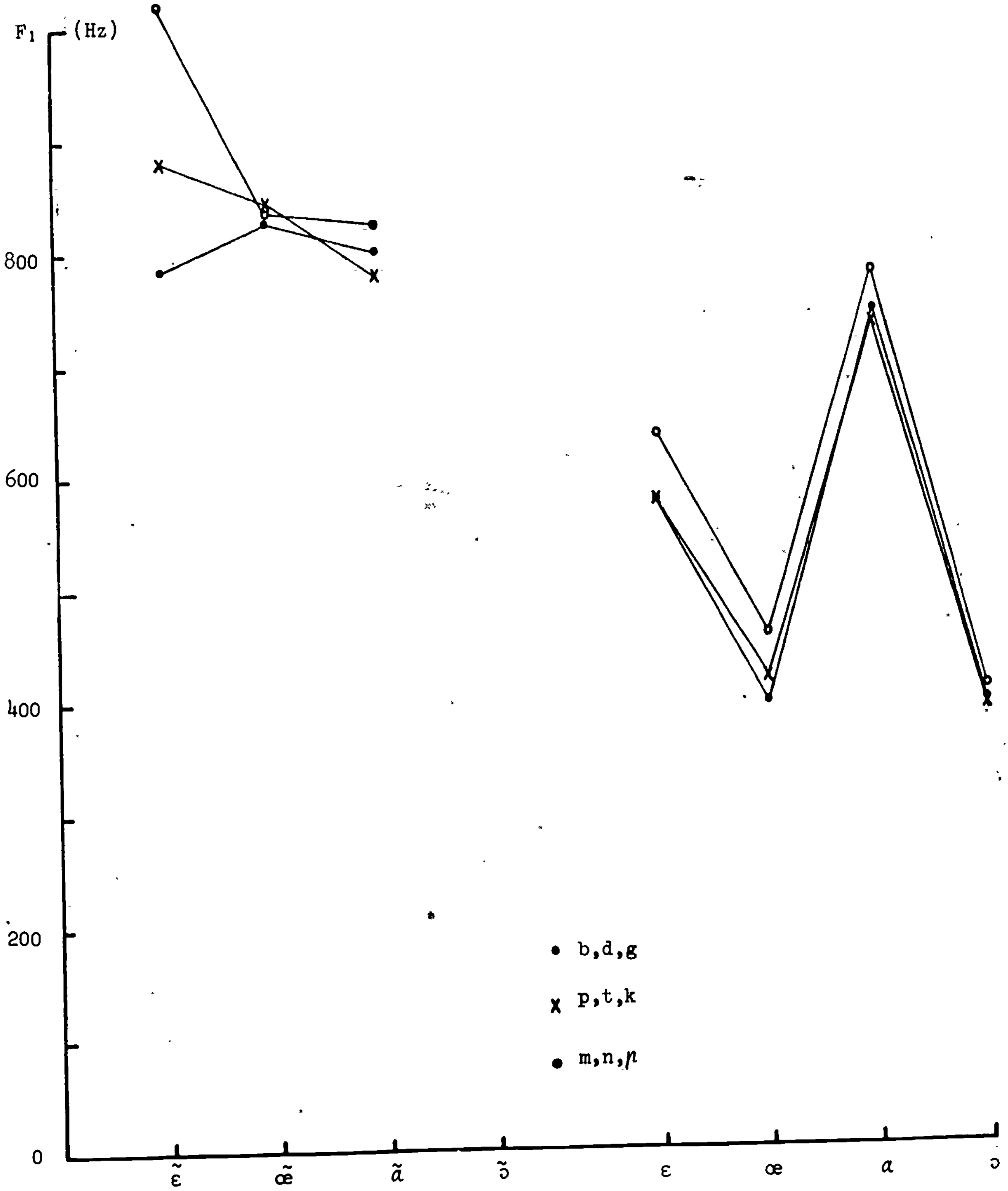
SLIDE [7]

a/ Formants and bandwidths of nasal vowels for speaker R.C.

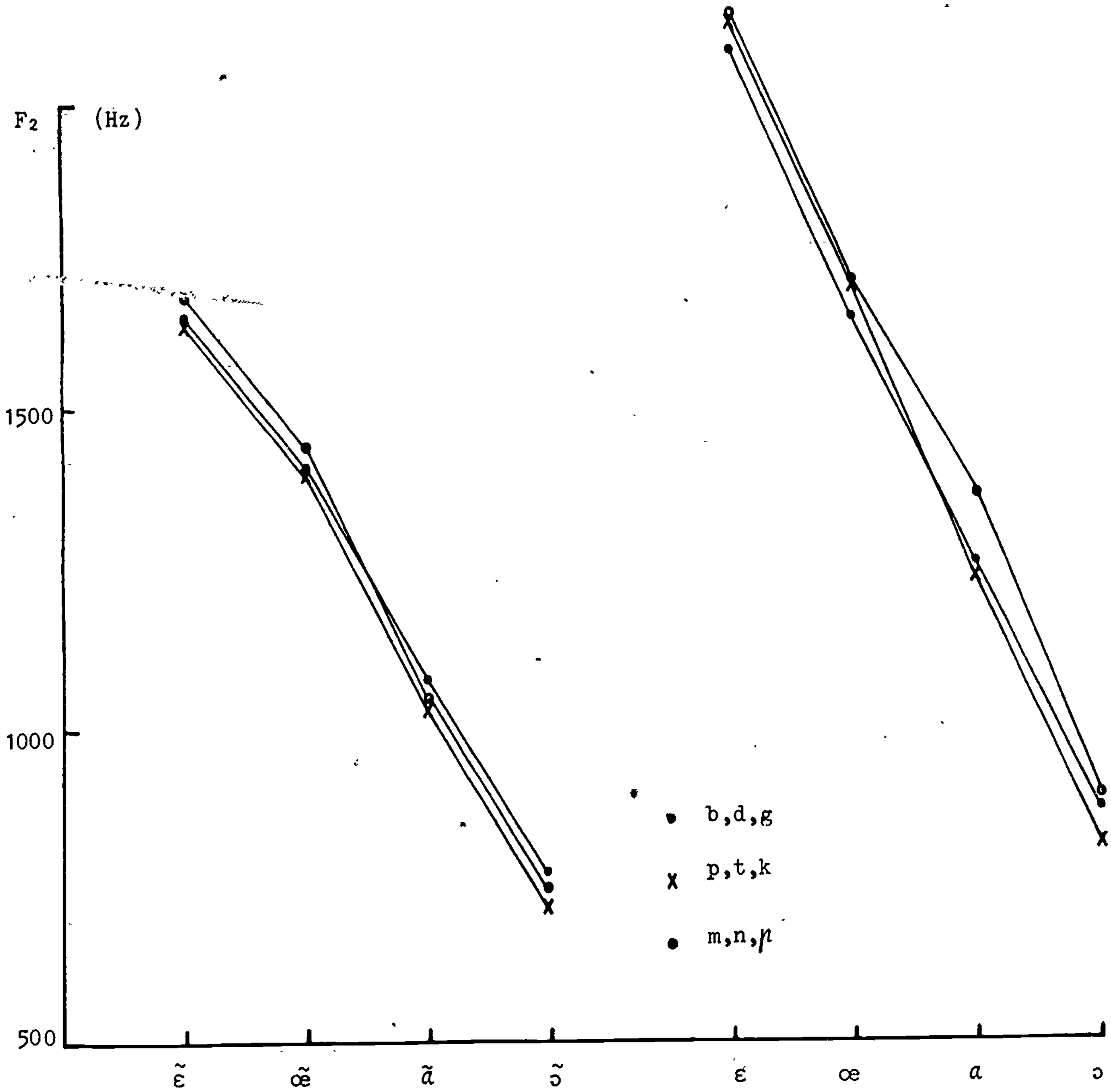
		F'_1	B'_1	F'_2	B'_2	F'_3	B'_3	F_{1N}	B_{1N}
ɛ̃	(b,d,g)	786(11)	295(88)	1748(96)	127(78)	3666(87)	388(96)	350(25)	59(9)
	(p,t,k)	882(36)	263(140)	1790(74)	146(60)	3612(86)	324(130)	362(15)	82(17)
	(m,n,ɲ)	1022(233)	327(100)	1903(240)	156(110)	3232(486)	358(124)	352(20)	84(40)
œ̃	(b,d,g)	830(80)	315(79)	1547(39)	148(51)	3046(27)	219(51)	345(15)	59(10)
	(p,t,k)	846(19)	308(51)	1566(91)	178(28)	3034(66)	312(151)	352(8)	72(25)
	(m,n,ɲ)	837(45)	271(48)	1664(125)	152(20)	3055(58)	195(49)	358(5)	95(64)
ɑ̃	(b,d,g)	801(37)	340(45)	1093(17)	112(20)	3492(164)	258(134)	362(6)	94(42)
	(p,t,k)	789(63)	212(34)	1118(25)	100(32)	3468(173)	200(65)	363(6)	80(35)
	(m,n,ɲ)	820(36)	201(117)	1199(52)	130(40)	3386(236)	235(11)	354(16)	79(36)
ɔ̃	(b,d,g)			808(47)	314(150)	3296(208)	200(50)	353(3)	115(57)
	(p,t,k)			712(49)	193(58)	3412(180)	249(50)	373(23)	111(65)
	(m,n,ɲ)			688(16)	236(150)	3452(59)	285(79)	350(10)	82(7)

b/ Formants and bandwidths of corresponding oral vowels for speaker R.C.

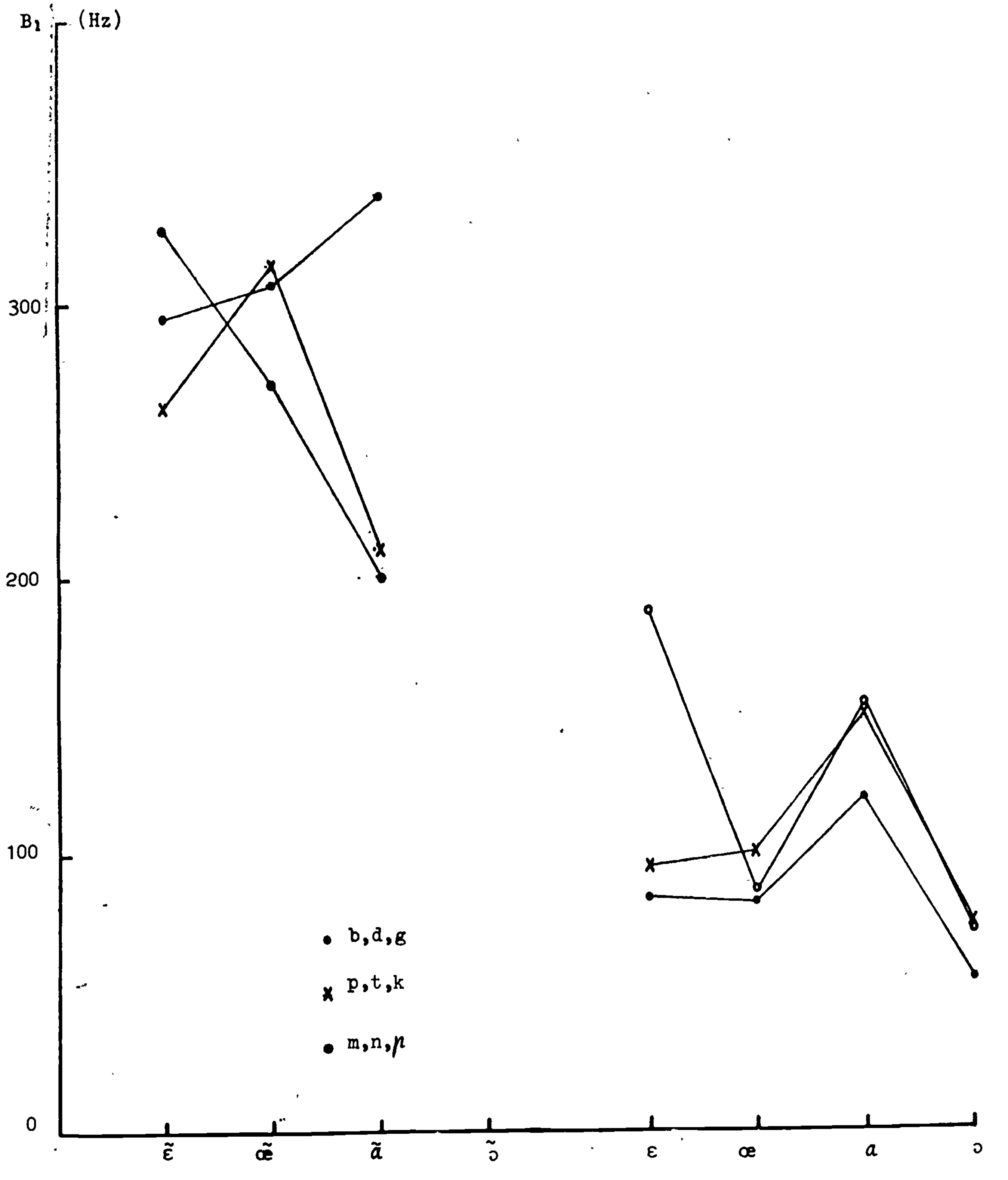
		F_1	B_1	F_2	B_2	F_3	B_3
ɛ	(b,d,g)	573 (14)	84 (14)	2074(72)	175(40)	2987(48)	378(78)
	(p,t,k)	573 (14)	97 (34)	2130(113)	235(20)	3216(360)	343(109)
	(m,n,ɲ)	632 (47)	188 (91)	2138(55)	179(50)	3110(26)	342(65)
œ	(b,d,g)	398 (20)	82 (8)	1652(13)	105(33)	2484(90)	110(21)
	(p,t,k)	419 (17)	101 (16)	1702(65)	108(12)	2450(59)	164(28)
	(m,n,ɲ)	459 (3)	86 (11)	1703(67)	97(15)	2520(24)	156(36)
ɑ	(b,d,g)	739 (28)	120 (27)	1258(29)	162(57)	3001(115)	178(34)
	(p,t,k)	731 (22)	150 (30)	1241(76)	285(32)	3000(146)	212(14)
	(m,n,ɲ)	774 (25)	154 (17)	1385(125)	236(55)	3041(139)	260(26)
ɔ	(b,d,g)	387 (4)	54 (2)	867(39)	194(17)	2684(69)	181(98)
	(p,t,k)	386 (9)	74 (17)	804(29)	198(29)	2629(27)	167(57)
	(m,n,ɲ)	389 (16)	72 (18)	896(119)	160(102)	2638(62)	125(73)



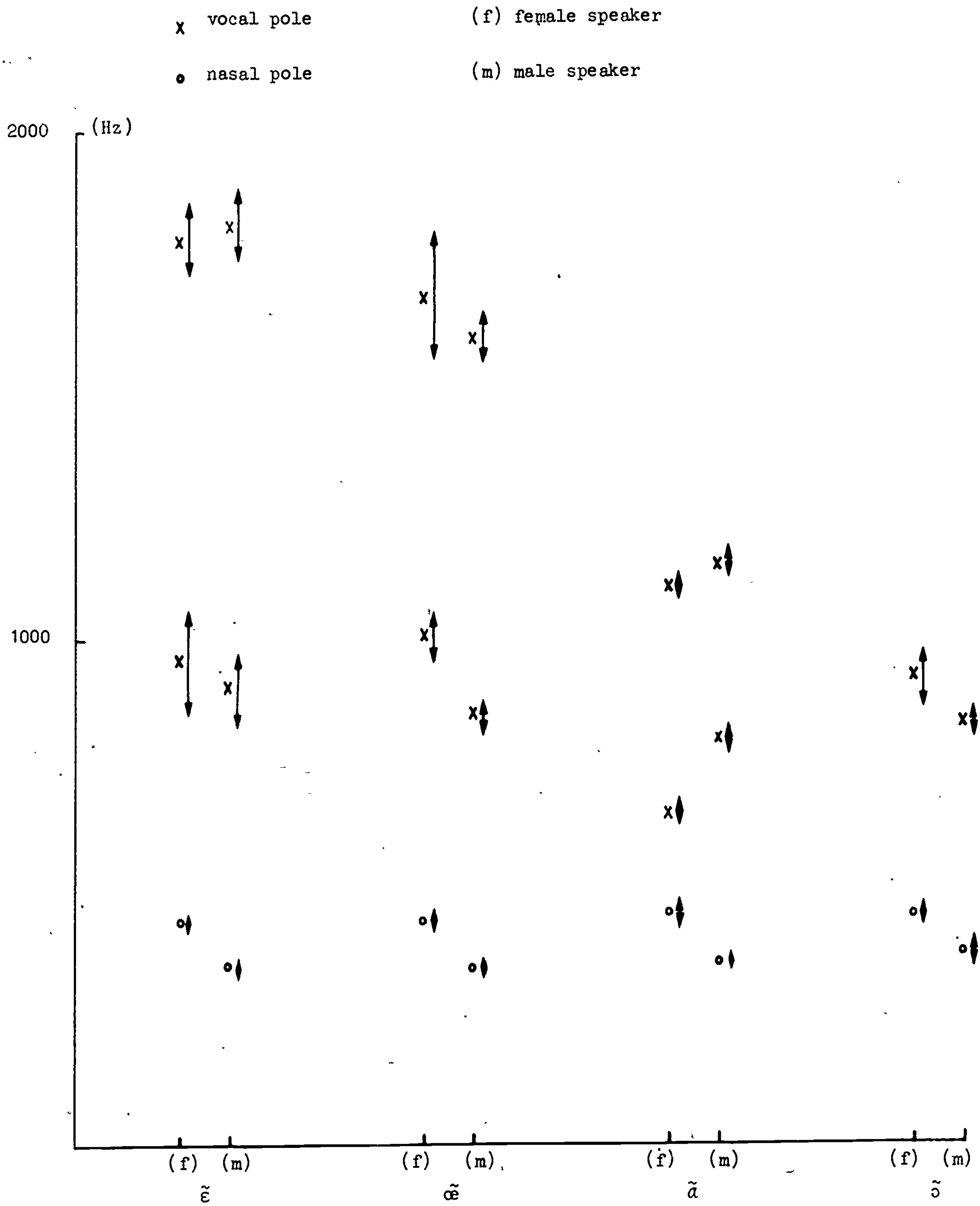
SLIDE [8] - First oral formant for nasal and oral vowels (speaker : R.C.)



SLIDE [9] - Second oral formant for nasal and oral vowels (speaker : R.C.)



SLIDE [10] - First formant bandwidth for nasal and oral vowels (speaker : R.C.)



SLIDE [11] - Nasal vowel formants for male and female speaker

Other features analysed are the duration of the nasal vowels which is found to ba one to two times longer than that of the oral vowels.

Another result realtes to intrinsic pitch. Contrary to the case of oral vowels [8], the fundamental frequency for the four nasal vowels was found to be the same on the average. This result could be explained by the coupling between the supraglottal cavities and the vocal source [4]. Other experiments are needed to verify this explanation.

CONCLUSIONS

The obtained experimental results are in complete agreement with the theoretical study developed by simulation. This study enables us to summarize the acoustic aspects of french nasal vowels as follows :

1. two nasal pole-zero pairs are introduce in the first and third formant regions
2. a stable nasal formant F_{1N} is characteristic of the individual speaker ;
3. oral first and third formants F'_1, F'_3 have a higher frequency and are less stable than those of the corresponding oral vowels. Otherwise, F'_2 is as stable as F_2 ;
4. F'_1 disappears in the case of the nasal vowel [ɔ̃] ;
5. nasal vowels have higher formant bandwidths than their corresponding oral vowels especially for the first formant F'_1 ;
6. the duration of nasal vowels is longer than that of oral vowels in the same context ;
7. all nasal vowels have about the same fundamental frequency.

In conclusion, these results can be used in speech recognition where the nasal vowels can be detected by their formant pattern and by means of bandwidth measurements.

Some of the found aspects, particularly F_{1N}, depend on the speaker and consequently can be used for speaker recognition.

In synthesis systems these data enable us to synthesize accurately nasal vowels. The four vowels were synthesized using a digital formant synthesizer having one nasal pole-zero pair. The obtained sounds are easily recognisable. However, we think that for french nasal vowels an additional nasal pole-zero pair would improve the quality of these vowels. Each vowel is recorded four times and they are presented in the following order [ɑ̃], [ɛ̃], [œ̃], [ɔ̃].

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