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Journal
Proceedings of the Annual Meeting of the Berkeley Linguistics Society, 4(4)

ISSN
2377-1666

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Publication Date
1978

Peer reviewed

ACOUSTIC CORRELATES OF "BIG" AND "THIN" IN KUJAMUTAY

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I. Introduction

Kujamutay[1] (Senegal) is the principal dialect of Diola,a member of the Bak sub-group of the West Atlantic branch of the Niger-Congo superstock (Greenberg,1963). Along with many other African languages it has a form of vowel harmony apparently found nowhere outside of Africa south of the Sahara (Stewart, 1971).

In the so-called "cross-vowel height harmony" languages the vowels form "two mutually exclusive sets such that (i) the tongue positions of the vowels of one of the sets are high in relation to the tongue positions of their counterparts in the other set,but (ii) the tongue position of at least one member of the relatively high set is lower than at least one member of the relatively low set (ibid:198). The vocalic contrast involved differs from the traditional tense/lax distinction drawn by Jakobson and Halle (1962) in so much as tense vowels are always situated more peripherally than their lax counterparts in a two-dimensional (F1 x F2) acoustic vowel space whereas the criterial dimension separating the African vowel pairs is relative vowel height.

The articulatory basis of the contrast has been the subject of some controversy. Stewart (1967) cites the radiographic data presented in Ladefoged's (1964) study of Igbo in support of the view that the major role is played by the tongue root. Complicating the issue,however,is the observation that the larynx tends to rise when the tongue root is retracted and to fall when the root advances. The opposing movements of tongue root and larynx consequently act to maximize or minimize the size of the pharyngeal cavity. Thus pharyngeal cavity size may be a more precise correlate of the cross-vowel height distinction than tongue root position (Lindau,1975).

Kujamutay is one of the comparatively few languages which possesses the cross-height harmony in its fullest form with five vowels in each of the contrasting sets. What makes the language even more noteworthy,however,is the social context in which the vocalic contrast functions. The meta-linguistic terms "big" (kələ) and "thin" (mis) are used by the Kujamaat[2] themselves to describe a systematic pattern of regional variation in vocabulary and pronunciation that is firmly rooted in the cross-vowel height harmony system (Sapir,1975).

In this paper we shall attempt to ascertain the depth to which this ethnolinguistic dichotomy penetrates the phonetic and acoustic strata of Kujamutay speech. In the following section we briefly outline Kujamutay phonology and vowel harmony,based on the considerably more detailed accounts presented in Sapir (1965) and (1975). Next,we discuss the pattern of interspeaker variation in vowel harmonization which is grounded in a basic contrast in the language's phonology. Finally,we examine the extent to which a similar pattern of interspeaker variation may exist in the acoustic features of Kujamutay speech.

II. Kujamutay Phonology and Vowel Harmony

Kujamutay has ten distinctive vowel phonemes[3] which divide into two equal sets such that the vowels of one set are always relatively higher than the corresponding vowels of the other set:

Relatively High Vowels		Relatively Low Vowels	
i̲	u̲	i	u
e	o	ɛ	ɔ
ə		a	

Coupled with this vocalic contrast is a general harmony rule which converts a vowel of the relatively low (L) set to its counterpart in the relatively high (H) set.[4] The harmony is triggered by certain grammatical elements and applies retrogressively in verb and noun inflection and in verbal and nominal root derivation. For example,the vowels in the word panalaañ ("he will return") undergo harmonization upon introduction of a set H vowel,the suffix -u̲ ("from"):

1(a) panalaañ "he will return"
(b) pənələəñu̲ "he will return from"

However,individual speech patterns vary with respect to the size of the linguistic domain over which the harmony applies. This fact was discovered during the course of an elicitation session with three kujamutay speakers. One of the informants pronounced the negative infinitive of the root -baj "to have" as kabajati rather than the expected kəbəjəti. Queried about this unusual form, the informant (AB) laughed and replied "We speak thin". The other two agreed, offering that they (AK, KB), in contrast, spoke "big".[5] KB's collective "we" referred to the people of Bignona, his home town and the local administrative center, as well as to the people of several adjacent villages from which the original inhabitants of Bignona had come some seventy-five years ago. In contrast, AK and KB came from outlying villages some 25 km from Bignona.

The speech of the three differed from each other in a number of ways:

A. Vocabulary. Certain Kujamutay words have optional forms with varying degrees of harmonization. In these instances, AB always used the relatively unharmonized variant, AK usually used the fully harmonized form, with KB's usage varying depending on the specific word:

	AB(Thin)	KB(Int)	AK(Big)	
2(a)	-kuntagɛn	-kuntejen	-kuntejen	"to kneel"
(b)	jifaruba	jifaruba	jifərubə	"storm"

B. Suffixes. Three suffixes have regional variants defined, in part, by the cross-vowel height contrast. With any of these suffixes, AB would invariably use the set L form, AK the set H variant, and KB's form would vary depending on the suffix:

	AB(Thin)	KB(Int)	AK(Big)	
3(a)	-ati	əti	-əti	neg infinitive
(b)	-ɛrit	-ɛrit	-urit	"never"
(c)	-uli	-uli	oli/-ɔli	1 pl. excl.

C. Harmony. However, neither the vocabulary nor the suffixes can by themselves, or together, provide a sufficient set of criteria for making the discrimination between "big" and "thin" speech. The Kujamaat are able to place someone as either a big or thin speaker without waiting for a diagnostic morpheme or lexical item. Some other, more pervasive, linguistic factor is at play and this other factor proves to be vowel harmony.

A "big" speaker will tend to carry the harmony further back than a "thin" speaker, though in fact, no absolute set of criteria apply to classify an individual's speech as "big" or "thin". Rather, a speaker is "big" only in comparison with another speaker whose speech, in turn, may be "big" relative to a third.

This pattern of interspeaker variation is evident in the harmony associated with infixed o . The hither marker -ulɔ-, when combined with the habitual -ɛ- reduces to o , which projects its harmonizing influence over the preceding verb form nabajɛbaj ("he always has") to varying degrees in the speech of our three informants. In the case of AK the infixed o casts its harmonizing spell over the entire verb form, it restricts its influence to the initial base verb for KB, and affects only the habitual marker -ɛ̲- in AB's speech:

4(a)	nəbəjeobaj	(AK:Big)
(b)	nabəjeobaj	(KB:Int)
(c)	nabajeobaj	(AB:Thin)

III. Acoustic Correlates of "Big" and "Thin"

Given the pervasiveness of the big/thin distinction in the phonology, might the contrast permeate the acoustic stratum of Kujamutay as well? To obtain an answer, we shall first examine the general acoustic features of the Kujamutay vowel system as exemplified in the speech of AK, KB and AB. We will then look at some of the acoustic dimensions more closely to determine whether a pattern of interspeaker variation analagous to that found in vowel harmonization occurs in the acoustic domain.

A. Vowel Spaces. A two-dimensional representation of the acoustic vowel space is shown for each speaker (Figures 1-3). Formant data shown in these and all other figures were obtained in the following manner; speech samples, derived from minimal or near-minimal pairs involving the cross-vowel height contrast were digitized from audio tape through a PDP-12 laboratory computer. The central portions of the vowels were spectrally analyzed based on linear prediction (Markel and Gray, 1975) to estimate the center frequencies of the first five formants.[6]

In Figures 1-3 the center coordinates of the ellipses represent the means for F1 and F2. A mean is typically based on three tokens, though the sample ranges between 1 and 8 items. The area circumscribed by the ellipse represents an ellipsoid-fitted estimate of the first and second formant ranges.[7] Formant frequencies were transformed from a linear frequency scale (Hz) into Mel units (Figure 10), which more closely approximates the function associated with the frequency resolving power of the ear (Stevens, Volkman, and Newman, 1937).

The vowel spaces deviate from the schematic representation of the Kujamutay system illustrated above in a number of ways:

(i) The seemingly mid-central vowel [əə] is in fact, rather far fronted, being practically contiguous with [e] and [ɛ]. Its set L counterpart [aa] is fronted only in AB's (thin) speech.

(ii) The mid-back vowel pair oo/ɔɔ has a greater vowel height separation than its mid-front counterpart e/ɛ.

(iii) The high-back pair u̲u̲/uu (and u̲/u as well) is lower than the high-front pair i̲i̲/ii. [oo] is considerably higher in relation to [uu] than the corresponding front vowels [e] and [ii] are to each other.

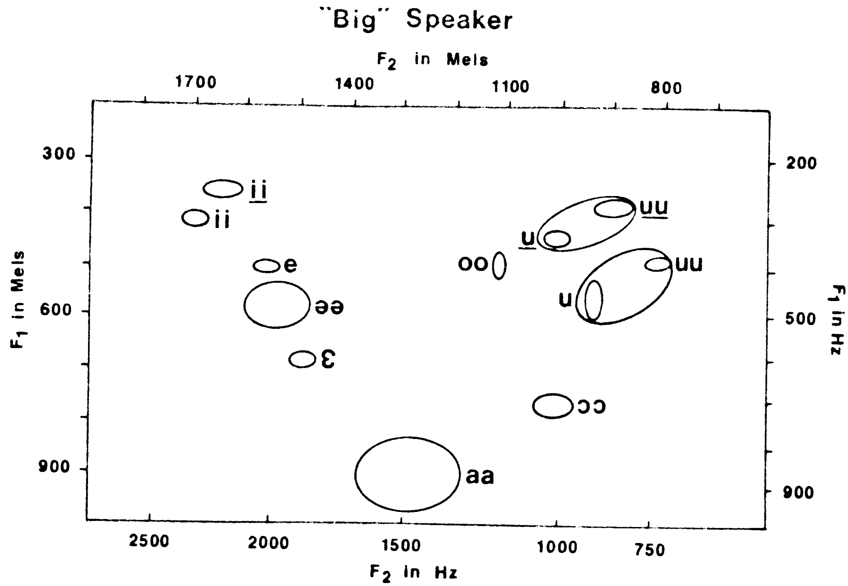


Figure 1 Two-dimensional acoustic representation of the vowel space for speaker AK. Non-homogeneity of vowel length due to composition of corpus.

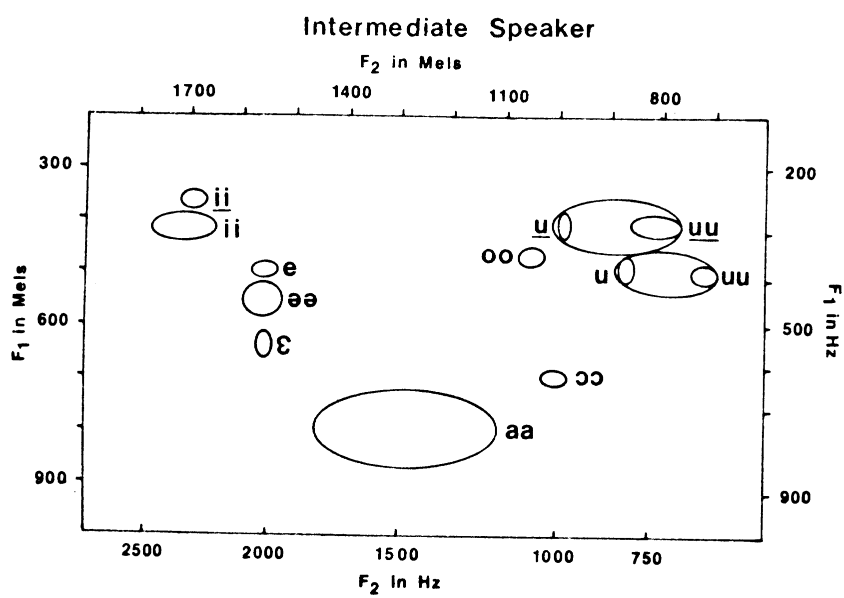


Figure 2 Acoustic vowel space for speaker KB.

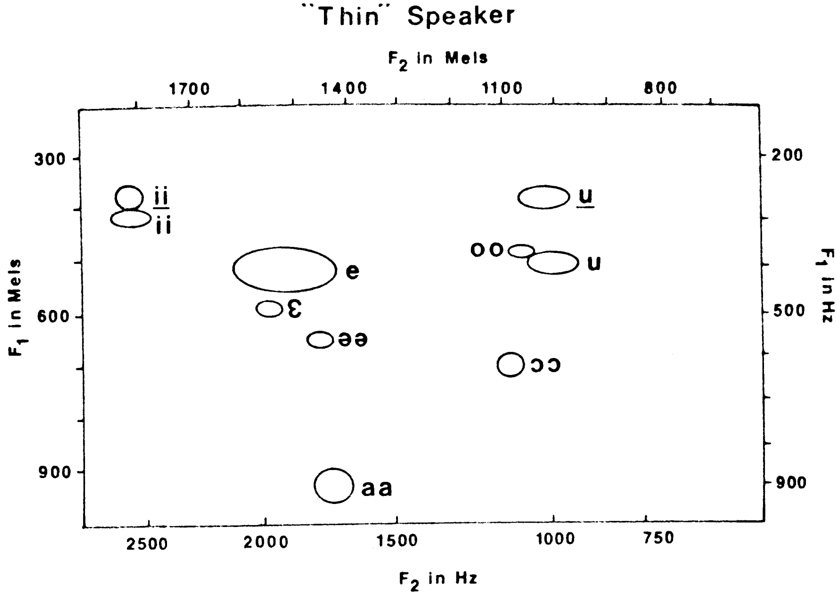


Figure 3 Acoustic vowel space for speaker AB.

B. Spectral Analyses. To determine the identity of the acoustic features most closely associated with the Big:Thin continuum, the spectra of selected vowels were compared along a number of acoustic dimensions (Tables I and II). Our goal was to determine which (if any) acoustic features analyzed displayed a consistent pattern of rank ordering among the three Kujamutay speakers. "Big" as KB's speech may have been, KB was considered by the other informants to be less of a "big" speaker than AK. And indeed, in terms of vowel harmony, vocabulary, and suffixing KB's behavior is in between the other two. Consequently, the appropriate rank ordering would place KB between AB and AK.

The results of this comparative analysis are presented in Tables I and II and in Figures 4-9. Table I includes the results of analyses involving all three speakers. Table II contains some additional data which were only available for AK and KB. Though discussion will be focussed on Table I, most of the general points apply to Table II as well. For the purposes of discussion, the results have been divided into four groups. Analyses involving comparisons of acoustic dimensions within a single vowel across the three speakers will be classified as single-vowel comparisons. Complementary-vowel analyses are those in which the comparison across speakers involves the differential of corresponding set H and set L vowels.

TABLE 1 (a)

Formant Frequencies for Single-Formant Dimensions:3 Speakers+

Vowel	Env	Formant 1 Big	Formant 1 Int	Formant 1 Thin	Formant 2 Big	Formant 2 Int	Formant 2 Thin	Formant 3 Big	Formant 3 Int	Formant 3 Thin	Formant 2' Big	Formant 2' Int	Formant 2' Thin
i̲i̲	k_k	353	362	382	1637	1698	1812	1910	1991	2094	1750	1818	1930
ii	k_k	416	413	411	1701	1724	1813	1917	2097	2066	1793	1869	1920
i̲i̲-ii	k_k	-63	-51	-29	-28	-26	-01	-07	-106	28	-43	-51	10
e	l_p	511	501	515	1556	1559	1520	1760	1832	1863	1641	1668	1648
ɛ	l_p	686	643	585	1491	1559	1542	1868	1823	1903	1619	1661	1673
e-ɛ	l_p	-175	-142	-70	65	00	-22	-92	09	-40	22	07	-25
e	l_l	515	487	544	1576	1561	1467	1852	1869	1828	1686	1681	1597
ɛ	l_l	684	616	640	1488	1578	1541	1830	1839	1947	1608	1681	1681
e-ɛ	l_l	-169	-129	-96	88	-17	-74	22	30	-119	78	00	-84
əə	l_n	582	547	649	1546	1558	1456	1786	1822	1890	1642	1663	1597
aa	l_n	886	791	932	1277	1285	1421	1836	1706	1909	1392	1399	1543
əə-aa	l_n	-204	-244	-283	269	273	35	-50	116	-19	250	164	54
oo	l_k	497	471	487	1120	1045	1065	1756	1862	1891	1276	1214	1235
ɔɔ	l_k	763	703	693	1012	1010	1086	1955	1812	1844	1110	1121	1215
oo-ɔɔ	l_k	-266	-232	-206	108	35	-21	-209	50	47	116	93	20
u̲	f_t	450	410	378	1012	1000	1018	1724	1431	1574	1169	1125	1167
u	f_t	569	477	501	936	886	1003	1795	1794	1871	1065	1027	1162
u̲-u	f_t	-119	-67	-123	76	114	15	-71	-363	-297	104	98	05

+ Data presented represent means of samples ranging from 2 to 8 tokens.

TABLE 1 (b)

Formant Frequencies for Multiple-Formant Dimensions:3 Speakers

Vowel	Env	Formant 2-Formant 1			Formant 2-Formant 1*			Formant 3-Formant 2			Formant 2'-Formant 1		
		Big	Int	Thin	Big	Int	Thin	Big	Int	Thin	Big	Int	Thin
ii	k_k	1320	1336	1430	10.92	11.02	11.56	273	293	282	1397	1456	1548
ii	k_k	1285	1311	1402	10.56	10.73	11.30	216	373	253	1377	1456	1509
ii-ii	k_k	35	25	28	.36	.29	.26	57	-80	-71	20	00	41
e	1_p	1045	1058	1005	8.66	8.79	8.36	204	273	343	1130	1167	1133
ε	1_p	805	916	957	6.48	7.33	7.77	377	264	361	933	1018	1088
e-ε	1_p	240	142	48	2.18	1.46	.59	-173	09	-18	197	149	45
e	1_1	1061	1074	923	8.75	8.96	7.69	276	307	361	1171	1194	1053
ε	1_1	804	962	901	6.47	7.72	7.29	342	261	406	924	1065	1041
e-ε	1_1	257	112	22	2.28	1.24	.40	-66	46	-35	247	129	12
əə	1_n	964	911	807	7.80	7.59	6.57	240	264	434	1060	1116	948
aa	1_n	391	494	489	3.22	4.14	3.89	559	421	488	506	608	611
əə-aa	1_n	573	517	318	4.58	3.45	2.68	-319	-157	-54	554	508	337
oo	1_k	623	574	578	5.61	5.26	5.27	626	817	816	779	743	748
ɔɔ	1_k	251	307	393	2.51	2.63	3.37	943	802	758	347	418	522
oo-ɔɔ	1_k	372	267	185	3.10	2.63	1.90	-317	15	58	332	325	226
u	f_t	562	590	640	5.16	5.44	5.88	712	431	556	719	715	789
u	f_t	367	409	502	3.23	3.76	4.56	859	908	868	496	550	661
u-u	f_t	195	181	138	1.93	1.68	1.32	-147	-477	-312	223	165	128

* Critical Band Units

TABLE 2

Formant Frequencies for All Dimensions:2 Speakers*

Vowel	Env	Formant 1 Big	Formant 1 Int	Formant 2 Big	Formant 2 Int	Formant 3 Big	Formant 3 Int	Formant 2' Big	Formant 2' Int	F2-F1 Big	F2-F1 Int	F2-F1+ Big	F2-F1+ Int	F3-F2 Big	F3-F2 Int	F2'-F1 Big	F2'-F1 Int
i̲	k_k	364	381	1609	1715	2119	1923	1790	1805	1245	1334	10.43	10.97	510	208	1426	1424
i	k_k	457	426	1680	1783	1980	1930	1800	1849	1223	1357	10.03	10.98	300	147	1343	1423
i̲-i	k_k	-93	-45	-71	-68	139	-07	-10	-44	22	-23	.40	-.01	210	61	83	01
e	j_l	511	479	1573	1611	1846	1863	1682	1714	1062	1132	8.77	9.38	273	252	1171	1235
ɛ	j_l	662	618	1500	1600	1818	1859	1615	1702	838	982	6.76	7.84	318	259	953	1084
e-ɛ	j_l	-151	-139	73	11	28	04	68	12	224	150	2.01	1.54	-45	-07	219	151
ee	r_s	498	511	1583	1652	1877	1857	1699	1739	1085	1141	8.97	9.29	296	205	1201	1228
ɛɛ	r_s	679	645	1498	1648	1878	1851	1628	1732	799	1003	6.45	7.89	380	203	949	1087
ee-ɛɛ	r_s	-181	-134	85	04	-01	06	71	07	286	138	2.52	1.40	-84	02	252	141
ə	l_n	576	492	1454	1399	1785	1827	1574	1544	878	907	7.27	7.78	331	428	998	1052
a	l_n	754	711	1242	1268	1736	1637	1365	1379	488	557	4.08	4.46	496	369	611	668
ə-a	l_n	-178	-219	212	131	-49	190	209	165	390	350	3.19	3.12	-165	59	387	384
o	l_k	585	543	1195	1173	1814	1717	1349	1319	610	630	5.26	5.51	619	544	764	776
ɔ	l_k	763	723	1057	1074	1960	1872	1168	1196	294	351	2.51	3.01	903	798	403	473
o-ɔ	l_k	-178	-180	138	99	-146	-155	181	123	316	279	2.75	2.50	-284	-254	361	303
u̲u̲	b_l	390	408	899	818	1596	1434	1046	941	509	410	4.69	3.72	697	616	656	533
uu	b_l	496	487	811	714	1721	1478	928	802	315	227	2.82	2.42	910	764	432	315
u̲u̲-uu	b_l	-106	-79	88	104	-125	-44	-118	139	194	183	1.87	1.30	-213	148	224	218

* Data in this Table not plotted in figures. Frequencies given in Mels unless otherwise noted.
\+ Critical Band Units.

A further division is made on the basis of whether the analysis involves single-formant or multiple-formant dimensions.

1. Single Vowel Comparisons. Direct comparisons of formant frequencies are, in general, hampered by the fact that differences between formant frequencies for the same vowel can vary as much as 30 per cent due to variation in vocal tract size (Fant, 1973). Consequently, any consistent rank ordering of single- or multiple-formant dimensions among speakers may be artifactual.

(a) Single-formant dimensions. Mean values for F1, F2, F3, and F2'[9] are presented in columns 1-4 respectively in Tables I and II. Data for F1 and F2 are also plotted in Figures 4 and 5. Inspection of the figures makes it clear that no consistent pattern of rank ordering prevails across vowels.

(b) Multiple-formant dimensions. Columns 5-8 of the tables contain similar data for the dimensions F2-F1, F3-F2, and F2'-F1. Again, no consistent pattern of interspeaker differentiation emerges from the analysis.

2. Complementary Vowel Comparisons. Given the failure of single-vowel analyses to extract any consistent pattern of interspeaker variation, we reasoned that if any systematic acoustic pattern correlated with the Big:Thin contin um did exist it would most likely be found in the acoustic relationship between structurally associated (corresponding set L and set H) vowels. A "big" speaker, exploiting the cross-vowel height harmony to a greater extent than a "thin" speaker, would tend to maintain greater articulatory, and hence acoustic, distance between set H and set L counterparts.

(a) Single-formant dimensions. The frequency differentials for F1, F2, F3, and F2' of corresponding vowels are shown in columns 5-8 of Tables I and II, as well as in Figures 6 and 7 for $F1^H - F1^L$ and $F2^H - F2^L$. It is clear from examination of the tables and figures that no consistent rank ordering occurs across all vowels.

(b) Multiple-formant dimensions. Results of analyses involving corresponding vowel differentials for the dimension F2-F1 are shown in Figures 8 and 9 for Mels and critical bands. The pattern of rank ordering and differentiation among the three speakers is quite close to the pattern of interspeaker variation exhibited in vowel harmony. The rank ordering is consistent all the way through for the data plotted in terms of critical bands and is nearly so for the same data plotted in Mels. The only exception is the pair ii/ii, which are often extremely similar in the West African vowel harmony languages.

IV. Discussion

What might the correspondence between the acoustic dimension $(F2-F1)^H - (F2-F1)^L$ and the phonological contrast Big:Thin signify? The dimension F2-F1 has a special status in both the auditory and articulatory domains. Acoustically, F2-F1

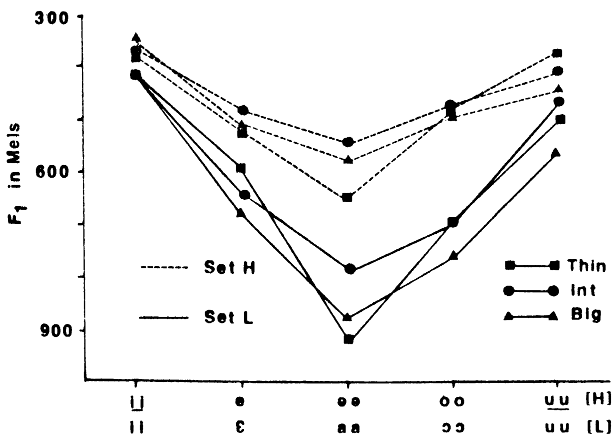


Figure 4 Mean values of first formant for five vowel pairs. Immediate consonantal environment identical for vowels of any single corresponding vowel pair.

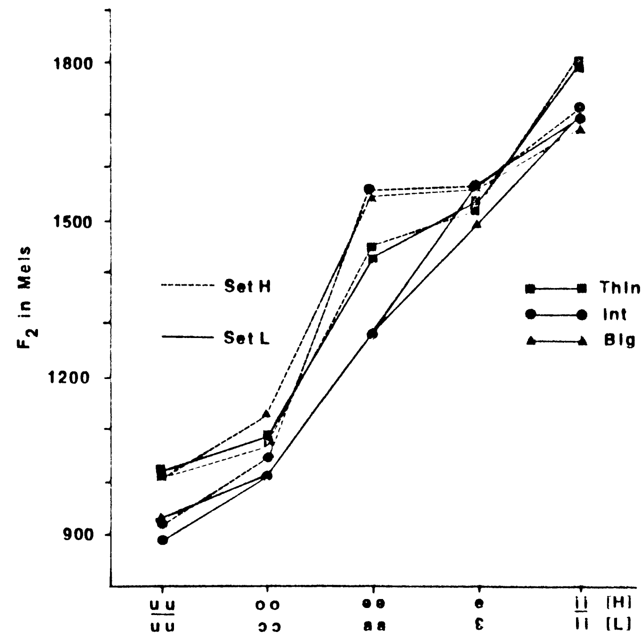
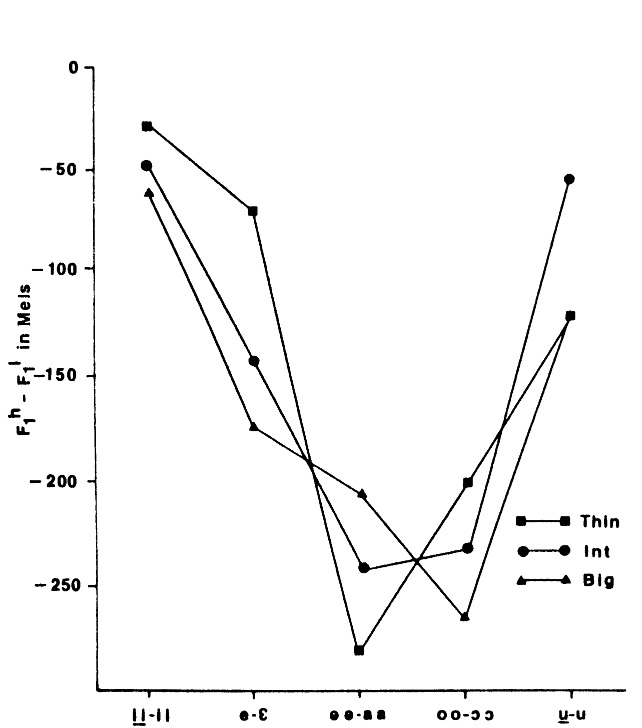
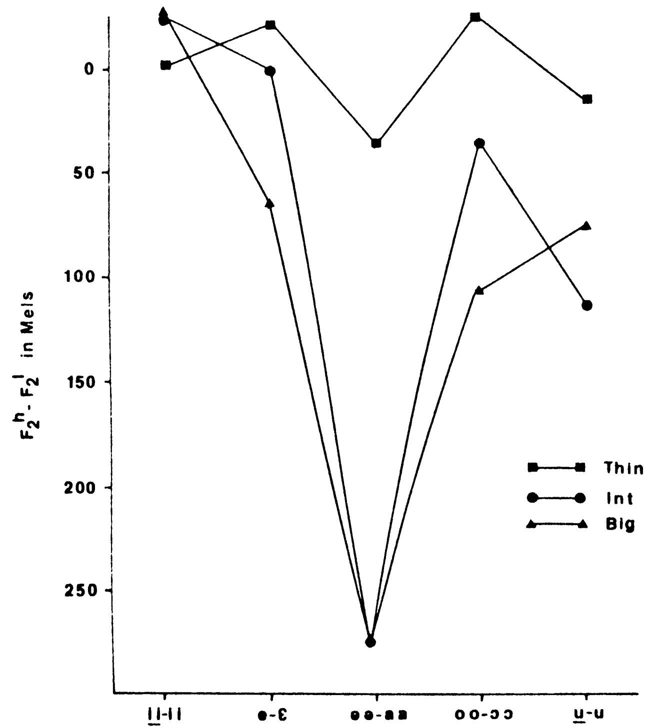


Figure 5 Mean values for second formant. Speakers are AK, KB, and AB.



<u>Figure 6</u> Figure 4 replotted to show the relationship between the first formants of corresponding Set H and Set L vowels.



<u>Figure 7</u> Figure 5 replotted to show the relationship of F2 in corresponding vowel pairs.

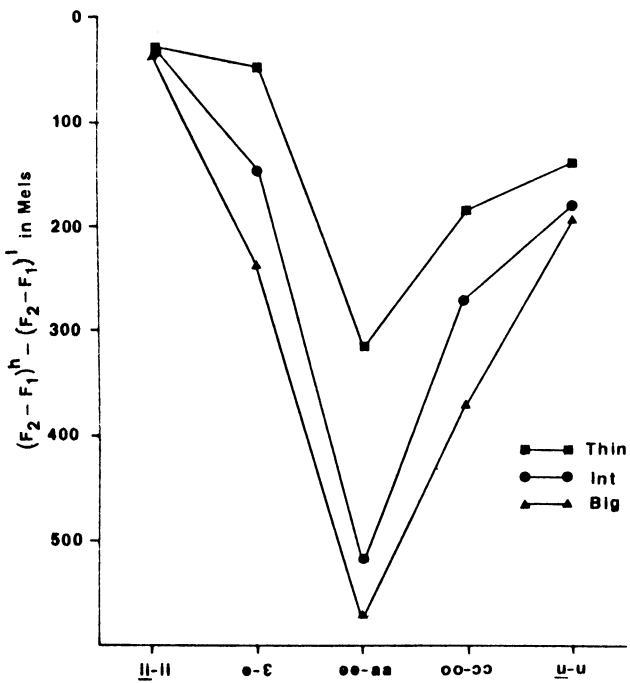


Figure 8 The relationship of the distance between the first and second spectral peaks (F2 - F1) for Set H and Set L counterparts is plotted in Mel units.

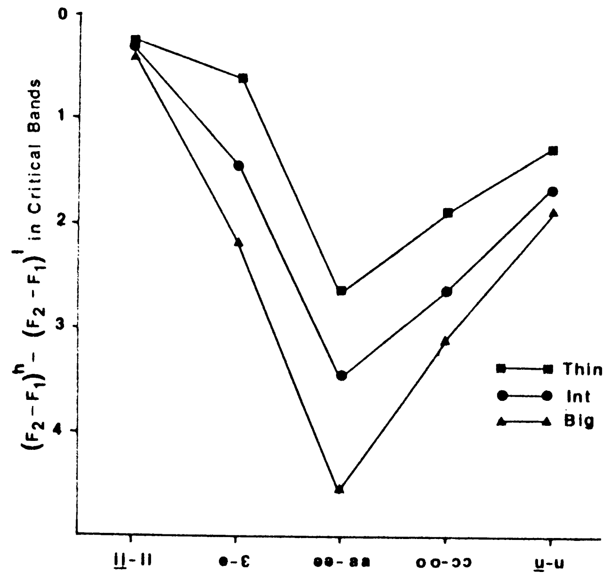


Figure 9 $(F2 - F1)^H - (F2 - F1)^L$ plotted in terms of critical band units.

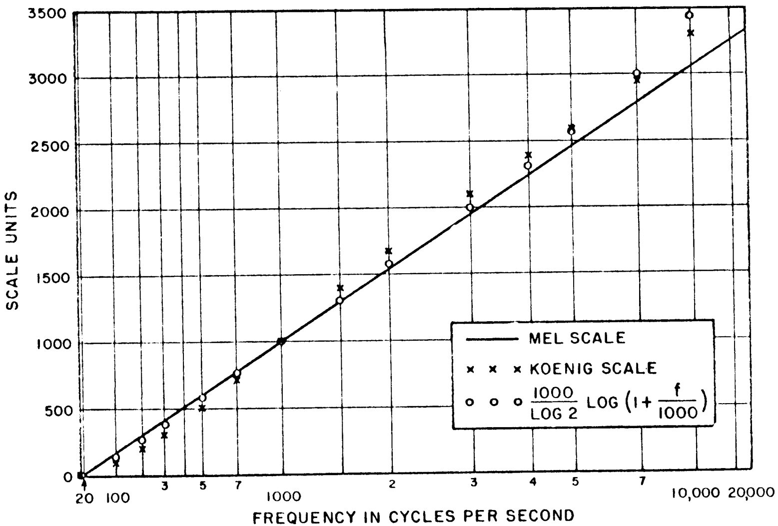


Figure 10 The relationship between a linear frequency scale (Hertz) and a scale derived from magnitude estimation studies (Mels). Also plotted is a technical approximation to the Mel scale. (From Fant,1973)

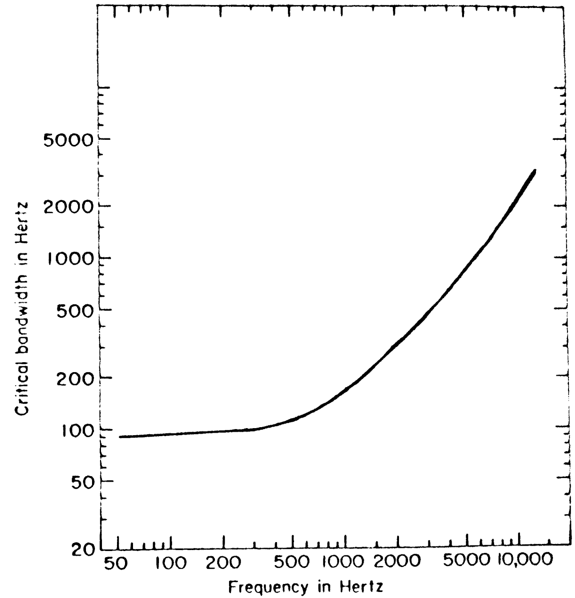


Figure 11 Critical bandwidth as a function of frequency. (Adapted from Scharf,1970)

corresponds to the contrast Grave:Acute (Jakobson, Fant, and Halle, 1952) - a feature which the cochlea appears to be rather sensitive to (Miller et al, 1977). The perceptual significance of F2-F1 for differentiating between "big" and "thin" in Kujamutay is suggested by the fact that a linear analysis of F2-F1 (Hertz) does not provide as reliable a basis for discriminating among the three speakers. The formant frequencies must be converted to a perceptually-relevant scale in order for the dimension to serve as a consistent differentiator.

Within the vowel-relevant range (250-3000 Hz) a fairly consistent relationship exists between the Mel scale and critical bands (Figures 10 and 11). One critical band equals approximately 100 mels (Lindsay and Norman, 1977). Though the critical band originated as a purely behavioral construct based on studies of loudness and frequency integration (Fletcher, 1940), it has been subsequently determined that it has a physiological correlate in the innervation density of auditory nerve fibers with the basilar membrane.[10]

In the articulatory domain, the dimension F2-F1 is highly correlated with the position of the tongue in the horizontal plane. As such, it provides a rather direct acoustic correlate of the contrastive articulatory feature Front:Back.

The prominent role played by F2-F1 in both the auditory and articulatory domains is not likely to be a matter of pure chance. Neither is it likely that this dimension could be so sensitive to the speech patterns associated with "big" and "thin" through the operation of coincidental factors.

V. Conclusion

The Kujamaat of Senegal socially intuit with the meta-linguistic terms "big" and "thin" a vowel contrast that is basic to their phonology. The two terms are used primarily to identify speech variation among individuals and groups. On the phonological level, speakers who make relatively greater use of vowel harmony are characterized as "big" in contrast to others who are thought of as "thin" speakers. On the acoustic level, the dimension F2-F1 is extremely sensitive to this same pattern of interspeaker variation. In so being, it demonstrates the depth to which a socially-motivated system of classification may penetrate a language.

NOTES

1. Referred to in previous publications (Sapir,1965;1975) as Diola-Fogny.

2. This is the name by which the speakers of Kujamutay refer to themselves as a social entity.

3. Length is phonemically distinctive in Kujamutay. Hence, the full complement of vowels numbers twenty when length is taken into account.

4. Occas ionally a set L vowel is converted to a vowel other than its own set H counterpart. See Stewart (1971) for a more detailed discussion on this phenomenon and its relation to diachronic processes in vowel harmony systems.

5. The distinction made by the Kujamaat between "big" and "thin" refers on a more basic level to the set H:set L contrast in the vowel phonology. It is not coincidental that the Kujamutay term for "thin" is mis with a set L vowel and that the word for "big" (kələ) is composed of set H vowels.
The pervasiveness of "big" and "thin" is exemplified by the fact that the contrast extends into the realm of sound symbolism. Like many other African languages,Kujamutay has a large vocabulary of qualifiers,known as ideophones, which serve to modify in particular ways both nouns and verbs. These ideophones frequently come in pairs,with one considered as being "more of","larger than","bigger than" the other. Many of the ideophonic pairs are distinguished by way of the cross-vowel height dimension,with the augmentative member of the pair always assuming the set H form. A good example of this type of contrast is jiker jelelel versus jikɛr jɛlɛlɛl. The verb -jiker glosses as "look out at,regard" and the ideophones refer to the glow or reflection in the eyes moving back and forth when they are caught in a beam of light. Thus:

    5(a) ebe ɛjikɛr jelelel "a cow looks with glowing eyes"
    (b) ɛjamɛn ɛjikɛr jɛlɛlɛl "a goat looks with glowing eyes"

6. Only the first three formants were analyzed in the present study.

7. The range was computed independently for F1 and F2 using the following equation: $r = \sigma(n/3)^{1/2}$,where n=sample size

8. Hertz were transformed into Mels using the technical approximation (Fant,1973): $Mel = \frac{1000}{\log 2} \log\left(1 + \frac{F(Hz)}{1000}\right)$

9. F2' is a weighted mean of F2 and F3. It was computed using the formula: $$F2' = F2 + 1/2\ (F3-F2)\ \frac{(F2-F1)}{(F3-F1)}$$ (Fant, 1973)

10. Approximately 1200 nerve fibers innervate the region of the basilar membrane spanned by a critical band (Lindsay and Norman, 1977).

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