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A crosslinguistic investigation of vowel formants in babbling*

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ABSTRACT

A cross-cultural investigation of the influence of target-language in babbling was carried out. 1047 vowels produced by twenty 10-month-old infants from Parisian French, London English, Hong Kong Cantonese and Algiers Arabic language backgrounds were recorded in the cities of origin and spectrally analysed. FI-F2 plots of these vowels were obtained for each subject and each language group. Statistical analyses provide evidence of differences between infants across language backgrounds. These differences parallel those found in adult speech in the corresponding languages. Implications of an early build-up of target-language-oriented production skills are discussed.

INTRODUCTION

The term 'babbling' denotes a specific form of production which appears between the ages of six and eight months for the majority of normally developing infants. Infants begin to babble when they utter sounds which exhibit acoustic timing constraints whose characteristics are close to those of mature speech (see Oller 1986 for the requirements that allow the label 'syllable' to be attached to infant production). The first patterning of babbling is mainly a reduplication of CV syllables. At around nine to ten

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months, syllabic combinations become more elaborated. Adults cannot recognize words or protowords in babbling productions.

What processes are involved in babbling? One view is that babbling is simply the natural output of an immature production apparatus, with no link to perceptual mechanisms. Another view is that perceptuo-motor attunements are already operating in babbling.

The first position can be referred to as the 'independence hypothesis'. It postulates that prelinguistic productions are constrained by universal maturational (physiological, biological) processes (Lenneberg 1967) and are thus universal. That is, they do not depend on the infant's linguistic environment. These constraints result in 'phonetic proclivities' (Locke 1983) or 'articulatory proclivities' (Lindblom 1984) which make infants utter subsets of adult-like productions. According to the independence hypothesis, motor and perceptual components of a language are considered to develop separately (Studdert-Kennedy 1986). Perceptual discrimination skills, already present in neonates, change as a result of the infants' exposure to the phonetic, phonological and intonational characteristics of their future mother-tongue. This leads to some early language-specific discrimination ability (Werker & Tees 1984), not apparent in babbling and first language productions. Although this does not necessarily imply that the linguistic environment cannot affect babbling, such a conclusion is generally drawn.

Inter-infant variability of babbling productions within the same linguistic community has been demonstrated both in sound repertoires and in the acoustic characteristics of productions (Ferguson 1979, 1986, Lieberman 1980, Vihman, Ferguson & Elbert 1986). Since inter-infant variability is ascribed to random variations depending on inherent factors, it is regarded as contradicting neither the claim that perception and production in infants are separate processes (Studdert-Kennedy 1986), nor the prediction of universality in babbling productions that follows from that claim.

The second position, 'interactional hypothesis', assumes that perceptuo-motor mechanisms begin to operate at the babbling stage. According to this hypothesis articulatory procedures that are mastered step by step are oriented by auditory configurations. At 10 months, articulatory control (Buhr 1980, Lieberman 1980, Kent & Murray 1982), together with the restructuring of the auditory system that takes place at around the same age (Werker & Tees 1984), allows infants to specify some vocal tract positions and permits them to produce language-oriented sounds (de Boysson-Bardies, Sagart, Hallé & Durand 1986, McCune & Vihman 1987).

Studies of the influence of a target language on babbling are few (Nakazima 1962, Weir 1966, Atkinson, MacWhinney & Stoel 1970, Olney & Scholnick 1976, Tuaycharoen 1979, Oller & Eilers 1982, Locke 1983, de Boysson-Bardies, Sagart & Durand 1984, Thevenin, Eilers, Oller & Lavoie 1985, de Boysson-Bardies *et al.* 1986) and draw conflicting conclusions. Some studies have found evidence of different patterns of babbling according to the target language. Listeners have been shown to be able to discriminate babbling of infants from different linguistic backgrounds (Weir 1966, de Boysson-Bardies *et al.* 1984, Ichijima 1987). Also, similarities in long-term spectral characteristic of adults and 10-month-old infants were found for French, Arabic and Cantonese (de Boysson-Bardies *et al.* 1986). On the other hand negative results are reported by Olney & Scholnick (1976) and Atkinson *et al.* (1970).

Prompted by the dominant independence hypothesis, most of the studies in the area have concentrated on the search for universal invariants in babbling through segment counts based on IPA transcriptions. Comparative studies have mainly been limited to frequency counts of consonants (for a comprehensive review, see Locke 1983). However, since the onset of babbling is marked by the appearance of syllabic productions with varied combinations of vowels and consonants, consonant frequency counts alone are not likely to be a good basis for crosslinguistic comparisons. Rather, such comparisons should be conducted through the close examination of both consonants and vowels. Phonotactic as well as the intonational and rhythmic patterns would also constitute necessary additional data for crosslinguistic comparisons of prespeech.

A cross-cultural study of babbling from infants reared in English and Spanish-speaking environments in Miami (Oller & Eilers 1982) showed that vowels belonging specifically to the sound inventory of Spanish are generally more frequent with children from the Spanish group while English vowels are on the whole more frequent with children from the English group. In particular, the vowel [æ] occurred with a frequency of 22·4% in English children, but only 13·5% in Spanish children. However, because of inter-subject variability, Oller & Eilers did not find any statistically significant differences in the overall sound inventories for the two groups.

During the past few years various authors have investigated the acoustic characteristics of vowel productions in the first year of life for infants from a single linguistic background. Their investigations have for the most part been restricted to children reared in English-speaking communities. In particular, the range of variation and average frequencies of the first three formants for 3-, 6-, 9- and 13-month-old infants from an American English background are available (Kent & Murray 1982, Kent & Bauer 1985). Lieberman's (1980) perceptual and acoustic investigation of the development of vowels in children 16 to 180 weeks old documented the gradual emergence of a vocalic space in early vocalizations. His study gives a week-by-week account of the evolution of average formant frequencies of different vowel sounds, although unfortunately only for those vowels which were recognized as English vowels. Lieberman observed that children produce formant frequency patterns 'equivalent' to adult ones, scaled to their shorter vocal tract lengths. This scaling evolves along with the growth of their vocal tract, but the coherence of their vocalic space is maintained. Lieberman also suggested that babbling children attempt to imitate sounds from their linguistic environment. Buhr (1980), working on the same body of data as Lieberman, observed that the production of vowel sounds in a 'quantal manner' appears at around 38–40 weeks, i.e. the variations between formant ranges of vowels become more stereotyped. According to Buhr, this could be explained by the stabilization of the anatomical configuration of the vocal tract.

While all the above authors note that the vocalic space of infants undergoes important modifications with time, they also emphasize the continuity of its development from birth to early speech. Acoustic studies of vowels in children reared in English-speaking communities yield some convergent conclusions – in particular, the evolution from a rather centralized vocalic space at the onset of babbling to a more spread-out space at the end of the first year, and the predominance of front over back vowels. Physiological and anatomical factors have been invoked to account for these trends (Buhr 1980, Kent & Murray 1982, Lindblom, MacNeilage & Studdert-Kennedy 1983). The authors also agree that there are important individual differences in sound repertoires, especially in the frequency counts of vowels produced by infants from the same linguistic background, in late babbling as well as in first words (Ferguson & Farwell 1975, Lieberman 1980, Kent & Bauer 1985, Ferguson 1986).

Because the infant's vocalic space seems to develop in a continuous and consistent way during the first year of life, the study of vowels in babbling should be particularly relevant to the hypothesis concerning the early effects of the linguistic environment. Since evidence for this hypothesis can only be provided by a comparison between different linguistic backgrounds, we conducted a crosslinguistic study of the acoustic characteristics of vowels in babbling.

The acoustic investigation of infants' vowels, limited here to the examination of the first two formants, was conducted using infant babbling productions from four different linguistic communities (French, English, Algerian and Cantonese). The aim of this study was twofold.

(1) To determine whether the independence hypothesis or the interactional hypothesis better characterizes infants' babbling. If babbling productions depend mainly upon universal maturational processes (the independence hypothesis), there should be no systematic differences among linguistic communities. If, in contrast, the target language influences productions (the interactional hypothesis), there should be systematic differences among linguistic communities.

(2) To determine whether inter-community differences, if found, reflect differences in adult speech.

TABLE *Distribution according to the nine classes, and total number of vowels transcribed for each of the twenty children*

		Proportion of vowels in each class									
		Front			Central			Back			Number of vowels
		High	Mid	**Low**	High	Mid	**Low**	**High**	Mid	**Low**	
English	**Mark**	0·009	0·126	0·288	0·009	0·369	0·135	0·018	0·027	0·018	111
	Carla	0·067	0·179	0·425	0.015	0·164	0·119	0·007	—	0·022	134
	John	0·024	0·178	0·476	0·083	0·137	0·083	—	—	0·018	168
	Sally	0·060	0·076	0·151	0·023	0·310	0·250	—	0·007	0·121	132
	Amely	0·061	0·024	0·411	—	0·202	0·239	—	0·006	0·055	163
French	**Olivier**	—	0.021	0·340	0·021	0·425	0·128	—	0·010	0·053	94
	Louise	0·011	0·056	0·124	0·006	0·333	0·435	—	0·022	0·011	177
	Odile	0·019	0·078	0·107	0·049	0·429	0·234	—	0·034	0·049	205
	Michel	0·005	0·065	0·427	—	0·205	0·140	—	0·011	0·146	185
	Julie	0·066	0·102	0·313	0·078	0·265	0·151	—	0·006	0·018	166
Algerian	**Sidali**	0·038	0·038	0·150	0·132	0·264	0·245	0·075	0·019	0·038	53
	Sam	0·050	0·129	0·137	0·079	0·201	0·209	—	—	0·194	139
	Rym	—	0·049	0·362	0·022	0·292	0·162	0·005	0·054	—	185
	Amine	—	0·013	0·347	0·040	0·133	0·413	—	0·053	0·054	75
	Zohra	—	0·076	0·367	0·063	0·139	0·278	0·013	—	0·063	79
Cantonese	**Kwan**	—	0·012	0·284	0·025	0·197	0·469	—	—	0·012	81
	Son	0·009	0·061	0·113	—	0·183	0·626	0·009	—	—	115
	Luk	—	0·021	0·197	—	0·176	0·549	—	0·035	0·021	142
	Tong	0·039	0·029	0·510	—	0·147	0·255	—	0·020	—	102
	Pearl	0·008	0·062	0·217	0·015	0·240	0·356	—	0·070	0·031	129

METHOD

Subjects

Twenty 10-month-old infants were recorded, five each in Paris, London, Algiers and Hong Kong. All the children were being raised in strictly monolingual households where only Parisian French, London English, Algerian Arabic and Hong Kong Cantonese were spoken. Children were paired for age and sex across language groups (see Table 2). Care was taken to ensure that the children had not been exposed to any other language or dialect. All 20 infants showed normal general and motor development.

Recording procedure

Recording sessions (one hour) took place in the children's homes in the presence of the mother. Both the mother and the experimenter were asked to speak as little as possible in order to avoid possible imitation. Recordings were made using a Sony TC-D5M cassette recorder with a Sennheiser MD 441 directional microphone. Care was taken to minimize the noise level, though this was not considered critical since subsequent processing was limited to the extraction of the first two formants. Because of the wide variety of cultures sampled, ideal recording conditions were unobtainable. Recording each child at home, in an environment where both mother and child were comfortable, allowed greater comparability across cultures.

Selection of vowels within babbling productions

Non-babbling sounds such as cries, squeals, growls and the like were first discarded. Out of the remaining productions, only the non-nasalized, non-diphthongized vowels which appeared within productions containing at least one consonant (i.e. in canonical or variegated babbling (Oller 1980, 1986)) were considered.

At this stage, the vowels retained were transcribed into narrow IPA by a single trained phonetician on the original tape recording, and further grouped into nine broad classes: High, Mid and Low Front, High, Mid and Low Central, High, Mid and Low Back. Table 1 shows the distributions across the nine classes and the total number of vowels transcribed for each child.

About 50 vowels per infant were then selected. For each infant, the analysed vowels were chosen so as to reflect the distribution of the vowels from the different classes in the infant's productions (see Table 1). Vowels were taken from the infant's babbling in order of appearance, provided that they were acoustically tractable (energy not too low, f_0 not too high). Selection continued until the proportions of tokens in the vowel classes matched those in the infant's productions. In polysyllabic productions, however, no more than one vowel per class was chosen (usually the first). Thus, in a production transcribed as [tatata], only the first [a] (Low Central) was selected. In [tatate], [e] being Mid Front, two vowels were selected. However, since the total number of tractable vowels per infant was different and since each class had to contain a whole number of vowels, the exact figure retained for an infant fluctuated around fifty vowels (see Table 2 for details).

Acoustic processing

For each vowel retained, a 30 msec portion was selected in the steady part by visual inspection of the waveform, sampled at 10 kHz. F1 and F2 were estimated from 20 Hz resolution short-time spectrum cepstrally smoothed by means of the 'true envelope' method (Imai & Abe 1979).

RESULTS

Independence versus interaction

For all the infants taken together, the overall ranges of variation are 400–1600 Hz for F1 and 1250–3800 Hz for F2. Mean F1 and F2 values, and standard deviations per infant, are presented in Table 2.

TABLE 2. *Mean formant frequencies and standard deviations (Hz) by subject*

Language	Infants	Sex	Age[a]	Number of vowels	Mean F1 and (S.D.)	Mean F2 and (S.D.)
English	Mark	M		53	818 (144)	2505 (394)
	Carla	F		63	842 (160)	2805 (383)
	John	M		50	782 (185)	2701 (294)
	Sally	F		64	962 (253)	2562 (569)
	Amely	F		52	969 (204)	2548 (482)
French	Olivier	M		58	814 (202)	2373 (337)
	Louise	F		47	758 (148)	2320 (417)
	Odile	F		69	956 (279)	2554 (489)
	Michel	M		61	864 (252)	2479 (423)
	Julie	F		61	953 (215)	2504 (475)
Algerian	Sidali	M		32	964 (296)	2411 (319)
	Sam	F		36	1050 (283)	2235 (376)
	Rym	F		54	924 (288)	2170 (401)
	Amine	M		54	1019 (258)	2247 (348)
	Zohra	F		61	948 (282)	2599 (583)
Cantonese	Kwan	M		42	951 (211)	2286 (501)
	Son	F		49	1072 (217)	2337 (303)
	Luk	F		60	1020 (243)	2566 (321)
	Tong	M		50	1061 (243)	2299 (318)
	Pearl	F		30	1173 (251)	2061 (272)
Overall				1047	938 (253)	2452 (451)

[a] Expressed as 10 months + days.

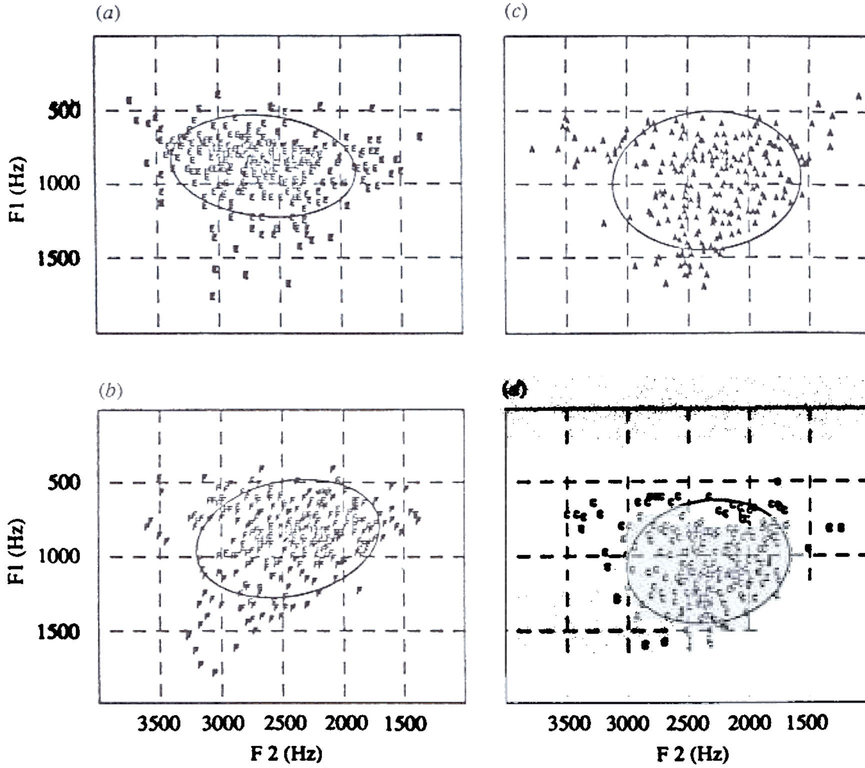

Fig. F1–F2 plots of all infant vowels for each of the four linguistic communities (75 confidence ellipses): (*a*) English, (*b*) French, (*c*) Algerian, (*d*) Cantonese.

In Fig. 1. the vowels (F1 and F2) are plotted by linguistic community, with 75 % confidence ellipses. Fig. 2 shows the detailed grouping by infant within each of the four linguistic communities. Mean F1 and F2 values and standard deviations, together with an F2/F1 ratio per linguistic community, are given in Table 3. This F2/F1 ratio characterizes the vowels on the compact-diffuse dimension, and at the same time, is little affected by variations of individual vocal tract length.

An analysis of variance run on the means of F1 and F2 for all infants, with a single factor, linguistic community, indicates a significant effect of this factor for F1, $F(3, 16) = 6.651$, $p < 0.01$, and for F2, $F(3, 16) = 4.728$, $p < 0.05$. There is a systematic difference between the means of formant frequencies of vowels of infants from different linguistic communities.

For a given infant, mean F1 and F2 define a 'mean vowel' which may be considered as an indication of the general trend for this particular infant's vowel productions. 'Mean vowels' for each child are shown in Fig. 3.

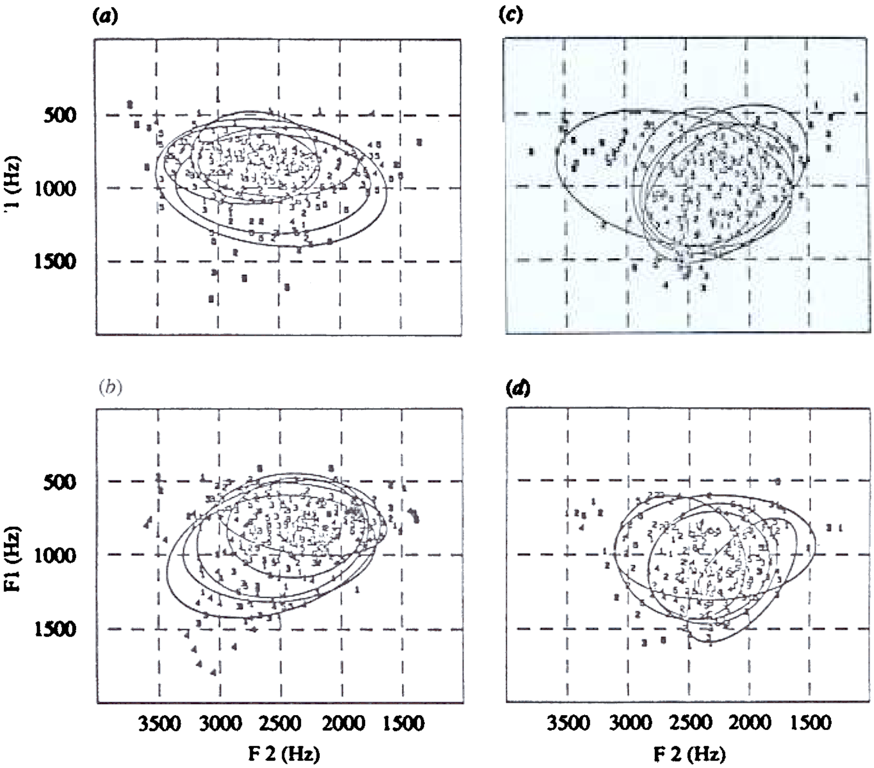

Fig. 2. F1–F2 plots of infant vowels, grouped by infant, for each of the four linguistic communities (75 % confidence ellipses): (*a*) English, (*b*) French, (*c*) Algerian, (*d*) Cantonese.

TABLE 3. *Mean formant frequencies and standard deviations (Hz) of infant vowels and F2/F1 ratios by language community*

	English	French	Algerian	Cantonese
F1		878 (239)		1047 (241)
F2		2456 (439)		2343 (381)
F2/F1		2·80		2·24

The 'mean vowels' occupy different sectors of the formant chart as a function of language background. However, six infants, two French, two English, one Algerian and one Cantonese, are close around the central position.

A second set of analyses was conducted, based on the computation of statistical distances between infants' vowel sets, so as to test directly the independence hypothesis.

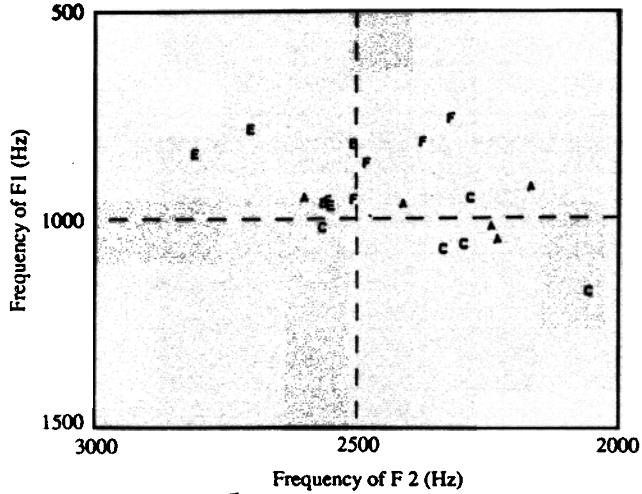

Fig. 3. F1–F2 plot of the 'mean vowels' of each infant; infants' linguistic group indicated by letter.

TABLE 4. *Intra-language and inter-language distances under the independence hypothesis (Ho)*

	English	French	Algerian	Cantonese
English	0·38	0·83	1·99	2·00
French		0·31	0·83	0·86
Algerian			0·42	0·86
Cantonese				0·45

Mean intra-language distances: 0·392.
Mean inter-language distances: 1·231.

If we assume that there are no significant differences between infants from different language backgrounds (Ho), distances between infants' vowel sets can be computed by means of a single Mahalannobis distance derived from this population (see Mardia (1977) and de Boysson-Bardies, Sagart & Hallé (1987); see also Appendix).

Table 4 summarizes the results under the independence hypothesis (Ho). Infants differ more between different linguistic communities (inter-linguistic community distances) than within any single linguistic community (intra-linguistic community distances) as indicated by a Student test ($t = 2{\cdot}76$, $p < 0{\cdot}05$). It is this which allows Ho to be rejected.

The independence hypothesis having been rejected, it is also of interest to test the hypothesis which predicts that there is one sub-population per

TABLE 5. *Intra-language and inter-language distances under interactional hypothesis (H1)*

	English	French	Algerian	Cantonese
English	0·46	0·47		1·36
French		0·29		1·00
Algerian				0·45
Cantonese				0·60

Mean intra-language distances: 0·440.
Mean inter-language distances: 0·767.

linguistic community (H1 hypothesis). In this way, we should get a more accurate estimation of the distances between inter-linguistic communities. A number of different Mahalannobis distances are now involved in the calculation to test H1.

Table 5 summarizes the results: averaged inter-linguistic community distances are larger than averaged intra-linguistic community distances.

To summarize, differences in vowels across linguistic communities already emerge in 10-month-old infants. In addition the interaction hypothesis yields an estimation of inter-linguistic community distances which might be useful when examining the second issue: is there a similarity with adult vowels?

Reflection on adult vowels

The main tendencies of infant vowels can be roughly visualized by means of what we called 'mean vowels', defined per infant or per language community. The F2/F1 ratio, an index of vowel compactness, is also informative in this respect, as will be seen below. In this section we attempt to give a similar account of mean vowels and F2/F1 ratios for adult speakers in the four languages under scrutiny.

We used two kinds of data from the existing literature on each language: frequency counts of vowels computed out of large corpora of running speech, and F1 and F2 mean values for individual vowels, found in exhaustive acoustico-phonetic studies involving a number of speakers. For each language, F1 (respectively F2) of the mean vowel was computed as the frequency-count-weighted mean of F1 (respectively F2) values from the acoustico-phonetic study.

For English (R.P.), French and Hong Kong Cantonese, we used frequency counts from Fry (1947), Wioland (1972) and Fok (1979) respectively. For formant values we used Henton (1983), Longchamp (in press) and Lee (1985) respectively. Data on Algiers Arabic could not be found, so instead we used data on Moroccan Arabic whose vocalic system is rather close to that of

Algiers dialect. Both frequency counts and formant values for Moroccan were found in Benkirane (1982).

Since nasalized and diphthongized vowels of babbling were not considered, nasalized vowels in French and diphthongs in English and Cantonese were not taken into account in this survey. As for all four languages, formant values for schwa were not documented, schwa had to be discarded from the mean vowel computation. F1 and F2 mean vowel values computed for English, French, Moroccan and Cantonese are shown in table 6 together with the F2/F1 ratios.

TABLE 6. *Mean formant frequencies (Hz) and F2/F1 ratios of adult vowels by language community*

	English	French	Moroccan	Cantonese
F1	459	465	506	536
F2	1692	1529	1534	1457
F2/F1	3·68	3·28	3·03	2·71

The same trends are found for adult speech and babbling: English and French have more diffuse vowels than Cantonese and Moroccan. The two most different languages in this respect, as with infants, are English and Cantonese in adult speech as well as in babbling. This could have been predicted from the examination of frequency counts for adults which indicate that English favours vowels which are high, front or both ([ɪ], [e] are the most frequent vowels not counting schwa) and Cantonese favours low, back vowels ([ɑː], [ɔː], [ɐ], are the most frequent vowels). Indeed, the implications of these trends agree with the fact that English has, on average, rather diffuse vowels and Cantonese rather compact ones.

DISCUSSION

The results support the fundamental claim of the interactional hypothesis that the variability in 10-month-old infant productions can be influenced by the characteristics of the linguistic environment. There is a close similarity between infant and adult vowels across the four linguistic communities examined here. This is best illustrated by the parallel patterns of the F1/F2 ratios found in infant and adult vowels. Such a conclusion challenges the dominant independence hypothesis. It reinforces the position that claims that there is a link between auditory and articulatory configurations and that the perceptuomotor system is already functional in the second half of the first year.

The early influence of environment shown in our data is not incompatible with trends generally thought of as universals. However, these trends, such as a tendency to centralize vocalic space, or the predominance of front vowels over back vowels, are modified by the characteristics of the vocalic linguistic environment. The ranges of values reported here for F1 and F2 are also consistent with observations on infants of similar age from American-English linguistic background (Buhr 1980, Lieberman 1980, Kent & Murray 1982): 700–1000 Hz for F1 and 2250–3000 Hz for F2. However, when infants from more than one linguistic community are studied together, a wider range of values is found.

From our data, inter-individual variability appears to be quite large: the first formant of infants' mean vowels varies from 758 Hz (one French infant) to 1173 Hz (one infant from Hong Kong), whereas the second formant varies from 2061 Hz (one infant from Hong Kong) to 2805 Hz (one English infant). Six infants (two English, two French, one Algerian and one Cantonese) out of the 20 cluster around the average values of F1 and F2, within the 900–1000 Hz range for F1 and the 2400–2600 Hz range for F2. The spreading of infants' vocalic spaces is also quite variable: some infants produce a wider spectrum of vocalic sounds than others. All this is in agreement with commonly observed inter-infant variability in babbling productions. Nevertheless, according to our results, the variability related to acoustic characteristics of vocalic space should not be ascribed to individual differences only, since inter-group differences have been found to be significantly larger than intra-group ones.

These systematic differences between groups cannot be attributed exclusively to physical differences in infants, such as vocal tract length, which are probably the most influential with respect to formant frequencies. Indeed, if the differences between two given groups were only a matter of vocal tract length, the scaling of formant frequencies would constitute the only difference, with both F1 and F2 yielding higher (or lower) values for a given group. This is far from the case. For example, in the case of the English and Cantonese groups, English infants' vowels have a lower F1, but a higher F2 than those of Hong Kong infants. Clearly, the difference does not lie in the scaling of formant frequencies. Though individual differences in vocal tract length cannot be denied, they do not appear to be systematically related to membership in particular linguistic communities. The systematic differences between infant groups fit better the differences between the average acoustic characteristics of vowels found in the adult languages.

F1 values for English infants are generally low (the mean F1 is 876 Hz, lower than for the Cantonese and Algerian groups) and only somewhat scattered. Mean F2 is higher than for any other group (2628 Hz). The average values of F1 and F2 observed by Kent & Murray (1982) in a group of 9-month-old American infants, about 900–1000 Hz for F1 and 3000 Hz for F2, agree better with our data for English infants than with those for any other group. The F2/F1 ratio is highest for English infants. It is also highest for English adults compared to French, Moroccan and Cantonese speakers. Individual English children do not depart from the general tendency of the English group, as shown in Fig. 2(a) and Fig. 3. In Fig. 3, all the mean vowels for English infants gather in the upper left part of the formant chart. This illustrates the preference of all English infants for diffuse vowels, in spite of individual variations.

F1 values for French infants are also low (mean F1 = 878 Hz). French mean F2 is between that for English and that for Cantonese. The F2/F1 ratio is lower than for English but higher than for Algerian and Cantonese infants. The same pattern was found in adult speech. As can be seen in Fig. 3, the mean vowels for French infants are closer to those of English infants than to those for the other groups, with a lower F2, which suggests a tendency towards a less fronted articulation.

Algerian infants have intermediate F1 values, and low F2 values, as low as for Cantonese. This parallels the preference for the Low Central vowel [a] in adult speech. The F2/F1 ratio is lower than for English and French, and higher than for Cantonese. Again, the same pattern was found in adult speech.

Infants in the Cantonese group show a preference for high F1 and low F2 vowels. Their mean F1 is higher than for any other group, and their mean F2 is as low as for the Algerian infants. The F2/F1 ratio is lower than for any other group, just as in adult speech. This suggests a marked tendency towards vowel compactness. Two infants depart from this general tendency, one for F1 and the other for F2 values. However, the mean vowels in the Cantonese group do not intermix with either the English or the French groups.

To summarize, we claim that the functional organization of the articulatory principles for speech in different languages begins during the babbling stage. In an earlier study (de Boysson-Bardies *et al.* 1986), we claimed that setting up loose articulatory limits to tongue and lip movements in vowel production could be the first step towards acquiring the vowel system of a target language. This implies that speech sounds in the surrounding language provide material for building the internal representations that infants use to try out articulatory patterns and configurations of the vocal tract. Werker & Tees (1984) indicate that there is a decline in the discrimination of non-native speech contrasts around 9–10 months and conclude that it is a function of specific language experience. We show that vocalic productions of infants around this age reflect some of the systematic differences in the mode of articulatory positioning that characterizes different languages. The data concerning perception and production tend to agree on the fact that the linguistic environment modifies the child's general abilities at the babbling stage.

According to Locke (1983:94) language acquisition begins 'when a child moves away from what would continue to be his pattern, and closer to the ambient one'. In Locke's view this takes place after the first fifty words have been acquired, when the rate of acquisition of lexical items increases markedly. In the present study we have shown that the build-up of language-oriented articulatory skills is already emerging at the end of the first year.

APPENDIX

Under Ho, all the infants' vowel sets are assumed to belong to a single population characterized with a covariance matrix Σ_a computed from all data. Σ_a defines the Mahalannobis distance for estimating distances between vowel sets of any two infants:

$$d^2_{ki,lj} = \Delta \Sigma_a^{-1} \Delta^T,$$

where k and l are indexes for linguistic communities, i and j indexes for infants within their linguistic communities, and Δ the vector of differences between Fi means ($i = 1$ to 2).

Average intra-linguistic community distances are computed according to

$$D_k = \left(\sum_{i=1}^{4} \sum_{j=i+1}^{5} n_{ki} n_{kj} d^2_{ki,kj}\right) \Big/ \left(\sum_{i=1}^{4} \sum_{j=i+1}^{5} n_{ki} n_{kj}\right) \quad (1)$$

where n_{ki} is the degree of freedom of the vowel sets and D_k the average intra-linguistic community distance within the kth linguistic community. Similarly, the averaged inter-linguistic distance between the kth and lth linguistic communities is given by:

$$D_{k,l} = \left(\sum_{i=1}^{5} \sum_{j=1}^{5} n_{ki} n_{lj} d^2_{ki,lj}\right) \Big/ \left(\sum_{i=1}^{5} \sum_{j=1}^{5} n_{ki} n_{lj}\right) \quad (2)$$

Under H1, infants' vowel sets are grouped by linguistic community. The kth linguistic community is characterized by the covariance matrix Σ_k.

Intra-linguistic community distances are:

$$d^2_{ki,kj} = \Delta \Sigma_k^{-1} \Delta^T,$$

while inter-linguistic community distances are obtained by averaging the covariance matrices of the linguistic communities involved:

$$d^2_{ki,lj} = \Delta \Sigma_{k,l}^{-1} \Delta^T,$$

where

$$\Sigma_{k,l} = (n_k \Sigma_k + n_l \Sigma_l)/(n_k + n_l)$$

and n_k is the degree of freedom of the entire vowel set of the kth linguistic community.

Averaged intra- and inter-linguistic community distances are computed as in (1) and (2).

REFERENCES

Atkinson, K., MacWhinney, B. & Stoel, C. (1970). An experiment in the recognition of babbling. *Psychological Review of Child language Development* **1**. 71–6.

Benkirane, T. (1982). *Etude phonétique et fonctions de la syllabe en arabe marocain*. Thèse de troisième cycle, Université d'Aix-en-Provence.

Boysson-Bardies, B. de, Sagart, L. & Durand, C. (1984). Discernible differences in the babbling of infants according to target-language. *Journal of Child language* **11**. 1–15.

Boysson-Bardies, B. de, Sagart, L., Hallé, P. & Durand, C. (1986). Acoustic investigation of cross-linguistic variability in babbling. In B. Lindblom & R. Zetterstrom (eds), *Precursors of early speech*. New York: Stockton Press.

Boysson-Bardies, B. de, Sagart, L. & Hallé, P. (1987). The influence of target language on vocalic space in ten-month-old infants. In *Proceedings of the Eleventh International Congress of Phonetic Sciences*. Tallinn, Estonia.

Buhr, R. D. (1980). The emergence of vowels in an infant. *Journal of Speech and Hearing Research* **23**. 62–94.

Ferguson, C. A. (1979). Phonology as an individual access system: some data from language acquisition. In C. J. Fillmore, D. Kempler & W. S. Wang (eds), *Individual differences in language ability and language behavior*. New York: Academic Press.

Ferguson, C. A. (1986). Discovering sound unit and constructing sound system: it's child's play. In J. S. Perkell & D. H. Klatt (eds), *Invariance and variability in speech processes*. Hillsdale NJ: Erlbaum.

Ferguson, C. A. & Farwell, C. B. (1975). Words and sounds in early language acquisition. *Language* **51**. 419–39.

Fok, A. (1979). The frequency of occurrence of speech sounds and tones in Cantonese. In R. Lord (ed.), *Hong Kong language papers*. Hong Kong: Hong Kong University Press.

Fry, D. B. (1947). The frequency of occurrence of speech sounds in Southern English. *Archives Néerlandaises de Phonétique Expérimentale*. 103–6.

Henton, C. C. (1983). Changes in vowels of received pronunciation. *Journal of Phonetics* **11**. 353–71.

Ichijima, T. (1987). *Infants' utterances during the babbling period: crosslinguistic analysis through perceptual and acoustic experiments*. Paper presented at the Poster Session of the International Society of Behavioural Development, Tokyo.

Imai, S. & Abe, Y. (1979). *Spectral envelope extraction by improved cepstral method. IECE, J62-A* **4**. 217–23.

Kent, R. D. & Bauer, H. R. (1985). Vocalizations of the one-year-old. *Journal of Child Language* **12**. 491–526.

Kent, R. D. & Murray, A. D. (1982). Acoustic features of infant vocalic utterances at 3, 6 and 9 months. *Journal of the Acoustic Society of America* **72**. 353–65.

Lee, T. (1985). The phonetic quality and long/short distinction of Cantonese vowels. *Fangyan (Dialect)* **1**. 28–38.

Lenneberg, E. (1967). *Biological foundations of language*. New York: Wiley.

Lieberman, P. (1980). On the development of vowel production in young children. In G. H. Yeni-Komshian, J. F. Kavanagh & C. A. Ferguson (eds), *Child phonology*. Vol. 1. *Production*. New York: Academic Press.

Lindblom, B. (1984). Can the models of evolutionary biology be applied to phonetics problems? In M. P. van der Broecke & A. Cohen (eds), *Proceedings of the Tenth International Congress of Phonetic Sciences*. Dordrecht: Foris.

Lindblom, B., MacNeilage, P. & Studdert-Kennedy, M. (1983). Self-organizing processes and explanation of phonological universals. In B. Butterworth, B. Comrie & O. Dahl (eds), *Explanations of linguistic universals*. The Hague: Mouton.

Locke, J. L. (1983). *Phonological acquisition and change*. New York: Academic Press.

Longchamp, F. (in press). Acoustique descriptive des sons du Français. In J. P. Tubach (ed.), *La parole et son traitement automatique*. Paris: Collection Scientifique et Technique des Télécommunications.

Mardia, K. V. (1977). Multivariate analysis. IV. In P. R. Krishnaiah (ed.), *Mahalannobis distances and angles*. New York: North Holland.

McCune, L. & Vihman, M. (1987). Vocal motor schemas. *Papers and Reports on Child Language Development* **26**. 72–9.

Nakazima, S. (1962). A comparative study of the speech development of Japanese and American English in childhood. *Studia Phonologica* **2**. 27–39.

Oller, D. K. (1980). The emergence of the sounds of speech in infancy. In G. Yeni-Komshian, C. Kavanagh & C. Ferguson (eds), *Child phonology: perception and production*. New York: Academic Press.

—— (1986). Metaphonology and infant vocalizations. In B. Lindblom & R. Zetterstrom (eds), *Precursors of early speech*. New York: Stockton Press.

Oller, D. K. & Eilers, R. E. (1982). Similarity of babbling in Spanish and English-learning babies. *Journal of Child Language* **9**. 565–77.

Olney, R. & Scholnick, E. (1976). Adult judgements of age and linguistic differences in infant vocalisations. *Journal of Child Language* **3**. 145–56.

Studdert-Kennedy, M. (1986). Sources of variability in early speech development. In J. S. Perkell & D. H. Klatt (eds), *Invariance and variability in speech processes*. Hillsdale NJ: Erlbaum.

Thevenin, D. M., Eilers, R. E., Oller, D. K. & Lavoie, L. (1985). Where is the drift in babbling? A cross-linguistic study. *Applied Psycholinguistics* **6**. 1–15.

Tuaycharoen, P. (1979). An account of speech development of a Thai child: from babbling to speech. In T. L. Thongkum, V. Panupong, P. Kullavanijaya & M. R. Tingsabadh (eds), *Studies in Thai and Mon-Kmer phonetics and phonology: in honor of Eugenie J. A. Henderson*. Bangkok: Chulalongkorn University Press.

Vihman, M. M., Ferguson, C. A. & Elbert, M. (1986). Phonological development from babbling to speech: common tendencies and individual differences. *Applied Psycholinguistics* **7**. 3–40.

Weir, R. W. (1966). Some questions on the child's learning of phonology. In F. Smith & G. A. Miller (eds), *The genesis of language*. Cambridge MA: M.I.T. Press.

Werker, J. & Tees, R. C. (1984). Cross-language speech perception: evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development* **7**. 49–63.

Wioland, F. (1972). Estimation de la fréquence des phonèmes en français parlé. *Travaux de l'Institut de Phonétique* **4**. 177–204.