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Progression of Acoustic Space in Early Years of Language Acquisition

Garima Dalal*

Abstract

This paper studies the acoustic space of children to describe how the development of speech especially the placement of vowels in young children 2 to 5 years of age takes place. The sounds produced by children right from their birth provide evidence concerning speech development. Researchers have usually focussed on the pre-word stage concentrating on speech and language of the child by analysing the speech sounds using a variety of techniques by usually. This paper is an attempt towards analysing the acoustic attributes of a child's vocal system focusing on the development of vowels in the second year of life, around one-word stage till the end of the fifth year when he grasps the language.

To gain an insight to early language acquisition the acoustic characteristics play a critical role. In this light, this work studies the formant patterns, formant frequencies and acoustic space of vowels produced by children. It presents a pictorial representation of the progression of acoustic space in young children using the first two formants of the vowels and shows significant results in the development of acoustic space. This work is based on a rich data of nearly two hundred participants and is an extension of a pilot study conducted by the researcher which involved six participants.

Key Words: Acoustic Space, Child Language Development, Vowels, Formants, Vowel Quadrilateral, Language Acquisition

Introduction

A lot of research has been conducted in the domain of acoustic phonetics still the acoustic space used by children in speech and language development is only partially understood. Such studies focus on the physical attributes of speech production of young children while others compare children's speech to adults' and have found that the former exhibits higher pitch and formant frequencies. Some studies also concentrate on describing the acoustics of speech of adults, but very few have analysed children's speech. Thus, due to lack of adequate data regarding the number of participants or the range of age of the participants, such studies have only been able to provide a limited amount of information on the acoustic patterns of speech of children. Hence, a need for a more chronologically detailed acoustic database from a larger representation with a wider range of age emerged to understand the developmental acoustic patterns in children's speech better. This study is an effort in this direction. As the child grows developmental changes take place anatomically, along with the development of their motor-control and cognitive abilities. These components affect the sounds produced, and some of the acoustic characteristics of these sounds may be the result of the size of the structures involved in speech production like the lungs, the larynx, the vocal tract, the oral and nasal chamber etc.

* Jawaharlal Nehru University, New Delhi

Jakobson in his celebrated paper, *Kindersprache, Aphasie, und Allgemeine Lautgesetze* (1941) was the first to implement the concept of linguistic feature to the stages of development of language. His most cited work in the study of vowel systems of child language acquisition revolves around his theory of phonemic development which deals with the sound structure of early speech. The principle of maximal perceptual contrast has a long tradition in linguistics (Jakobson 1941; McNeill 1970). This principle suggests that a vowel system tends to achieve a maximum contrast among the vowels in the system and dictates the order of acquisition of phonological oppositions. In general, the broad variations are acquired first, and gradually the distinctions become more refined.

The present research focuses on the acoustic parameters especially the first two formants. Formants play a very crucial role in the determination of the vowel sounds (Fry 1979:76). They are characterised by their first, second, and third formants (F1, F2, and F3) (Fry, 1979). A vowel's formants are the frequencies at which it resonates; that is, the frequencies which are particularly loud in an acoustic signal. Each vowel has its own set of specific formants. The resonances of the vocal tract are formants. They are dependent on the overall shape and size of the cavities above the larynx (Catford 1988:160). These formants play a crucial role in the determination of vowel sounds (Catford 1988:126). This study investigates the size of vowel spaces used by speakers, i.e. the size of the "working" vowel space (in the F1 x F2 plane) used by the participants. A vowel space is defined by a speaker's range of first formant (F1) and second formant (F2) frequencies. We identify vowels by the patterns formed by their formants within that acoustic space. F1 corresponds to the height of vowels and F2, or F2-F1 corresponds to the front/back-ness of vowels.

According to Kent et al. (2007), several studies have worked on "age-related variability of formant-frequency pattern in vowel production". He further states that the earliest study was a cross-sectional study by Eguchi and Hirsh (1969), which explored the variability of F1 and F2 in children aged from 3 to 11 years of age. The work of Nittrouer (1993) followed who described F1 variability being minimal at 3 years of age while F2 continued to decrease.

As an extension of the earlier preliminary pilot study, this study explores the development of vowels in an acoustic space in groups of children from the Group 1 starting from 2 years 5 months to Group 10 aged 5 years 8 months. It also explores the emergence of vowel contrast across the 10 groups and examines if the vowel height distinction is acquired earlier than the front and back distinction.

Experiment Design

This is a cross-sectional study of children from a similar socio-economic and cultural background where Hindi and English words are a part of the entire verbal repertoire. The select sample was based on criteria such as age, gender, languages known, and a similar socio-economic background. All the participants were from pre-nursery to lower kindergarten in North-West Delhi region. Initially, a random selection of 200 children was made, and data was collected, but after a careful evaluation of the samples gathered some samples had to be left out due to errors, bringing the numbers down to 185. Further, for an equal representation the male-female participants were divided in equal numbers within their respective groups. Thus it is the study of the data of 160 children. i.e. Male-Female (80+80) participants from 2 years 5 months to 5 years 8 months old (See Table 1 in Appendix).

The present study examines the size of vowel spaces encompassing seven peripheral vowels /i, e, ɛ, a, ɔ, o, u/ for both Hindi and English (14 in all). Words from child repertoire were selected, and a specific word list was prepared to include all the peripheral vowels in the CVC position. This data was collected over a year with the help of picture charts, flash cards and pictures on powerpoint to make the child more comfortable especially for the younger participants. The data from each participant was recorded in a regular, quiet room, in the presence of the participant's parents or caretaker or nanny near them. A digital voice recorder Sony ICD-PX820 was used for the recordings. Goldwave was used for noise reduction, and PRAAT was used for the analysis of the sounds. The details of the participants were kept confidential since they are a part of vulnerable population and ethical norms were strictly adhered to.

Data Analysis

The participants were divided into ten groups (from A1 to A10) based on their age, for comparison by their age. Other than the groups A1 – A10 the youngest informant who is 2 years 1 month 5 days old was assigned Group -1 and the eldest who is 5 years 11 months 13 days was assigned Group 10+.

Since the study primarily focuses on the acoustic parameters, especially the first two formants F1 and F2 where F1 represents vowel height, and F2 or F2-F1 represents the front-back criteria, the formant values were calculated and plotted for all the 7 peripheral vowels of both English and Hindi by taking their averages and combining them for both male and female participants taken for the study. This is done for each group individually. An equal number of male-female (80+80) participants were divided into different groups with a gap of 4 months from 2 years 5 months to 5 years 8 months old (See Table 1 in Appendix).

Thus, for Group A1 the averages of the formants for each peripheral vowel of both English and Hindi for all five Male (M1) and five Female (F1) participants in the group were averaged. Thus an overall average value for the seven peripheral vowels irrespective of gender and language was calculated. The values of the first two formants namely F1 and F2; were extracted. The – F1 values were plotted along the y-axis and – (F2-F1) values along the x-axis, to arrive at the visual representation of their acoustic space corresponding to articulatory vowel space, like a cardinal vowel chart. The formant values and Group-wise details of the participants have been discussed.

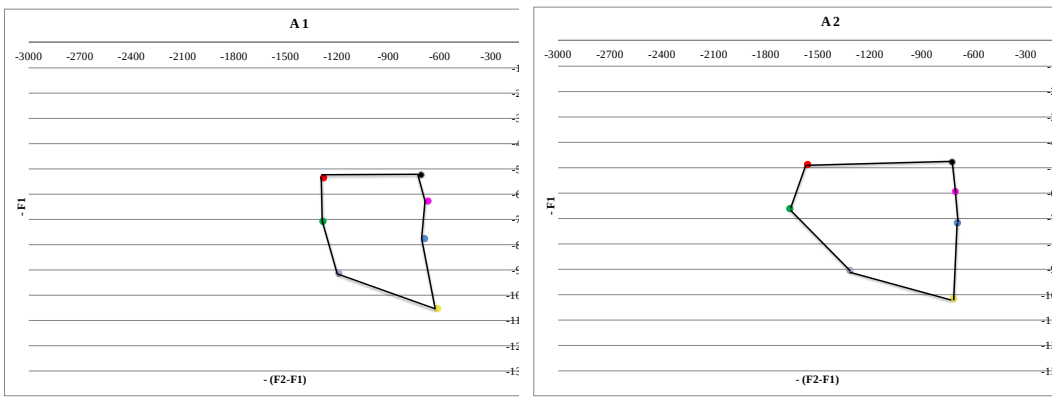

Figure 1: Graphical representation of Acoustic space of A1 and A2

Group A1 comprises of 5 males and 5 females aged between 2 years 5 months (2Y5M) to 2 years 9 months (2Y9M). There are 2 females aged 2Y5M, 2 females and 3 males aged 2Y6M, 2 males aged 2Y7M and 1 female aged 2Y8M. The children in this age group have the lowest (F1) value as 523 Hz and highest as 914 Hz. For (F2-F1) we find the lowest as 613 and highest as 1283 Hz. Thus the range for (F1) is 389 Hz and for (F2-F1) is 670 Hz. Group A2 comprises of total 12 participant including 6 males and 6 females aged between 2Y9M to 3Y1M. There are 2 females and 2 males aged 2Y9M, 1 female and 2 males aged 2Y10M, 2 females and 1male aged 2Y11M and; 1 female and 1 male aged 3Y0M.The participant in this age group have the lowest (F1) value as 476 Hz and highest as 1014 Hz. For (F2-F1) we find the lowest as 697 and highest as 1663 Hz. Thus the range for (F1) is 538 Hz and for (F2-F1) the range is 966 Hz.

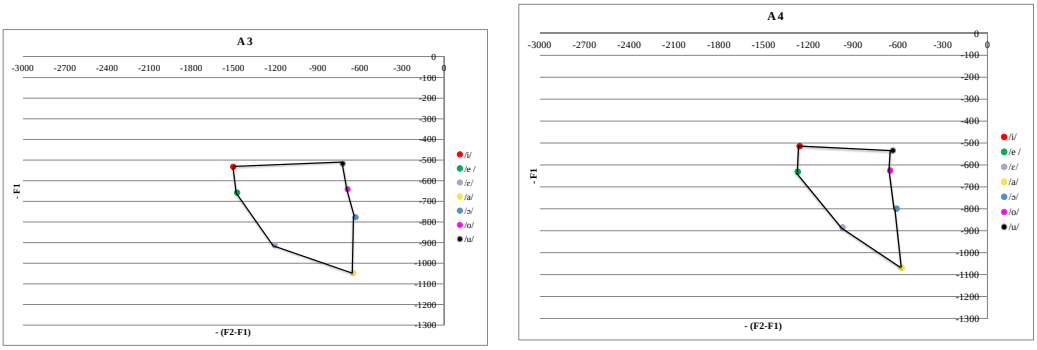

Figure 2: Graphical representation of Acoustic space of A3 and A4

Group A3 comprises of total 14 participant including 7 males and 7 females aged between 3Y1M to 3Y5M. There are 1 female and 2 males aged 3Y1M, 2 female and 2 males aged 3Y2M, 2 females and 2 male aged 3Y3M and; 2 female and 1 male aged 3Y4M. The participant in this age group have the lowest (F1) value as 516 Hz and highest as 1045 Hz. For (F2-F1) we find the lowest as 632 Hz and highest as 1504 Hz. Thus the range for (F1) is 529 Hz and for (F2-F1) the range is 872 Hz. Group A4 comprises of total 16 participant including 8 males and 8 females aged between 3Y5M to 3Y9M. There are 3 female and 2 males aged 3Y5M, 1 female and 2 males aged 3Y6M, 2 females and 2 male aged 3Y7M and; 2 female and 2 male aged 3Y8M. The participant in this age group have the lowest (F1) value as 513 Hz and highest as 1067 Hz. For (F2-F1) we find the lowest as 575 Hz and highest as 1273 Hz. Thus the range for (F1) is 554 Hz and for (F2-F1) the range is 698 Hz.

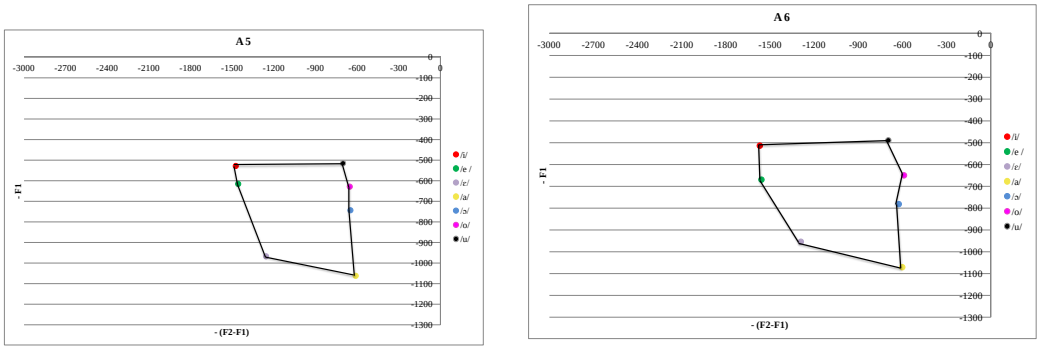

Figure 3: Graphical representation of Acoustic space of A5 and A6

Group A5 comprises of total 16 participant including 8 males and 8 females aged between 3Y9M to 4Y1M. There are 2 females and 2 males aged 3Y9M, 2 female and 2 males aged 3Y10M, 2 females and 2 male aged 3Y11M and; 2 female and 2 male aged 4Y0M. The participant in this age group have the lowest (F1) value as 514 Hz and highest as 1060 Hz. For (F2-F1) we find the lowest as 612 Hz and highest as 1476 Hz. Thus the range for (F1) is 546 Hz and for (F2-F1) the range is 864Hz. Group A6 comprises of total 18 participant including 9 males and 9 females aged between 4Y1M to 4Y5M. There are 2 females and 3 males aged 4Y1M, 3 female and 2 males aged 4Y2M, 2 females and 2 male aged 4Y3M and; 2 female and 2 male aged 4Y4M. The participant in this age group have the lowest (F1) value as 488 Hz and highest as 1069 Hz. For (F2-F1) we find the lowest as 591 Hz and highest as 1571 Hz. Thus the range for (F1) is 581 Hz and for (F2-F1) the range is 980Hz.

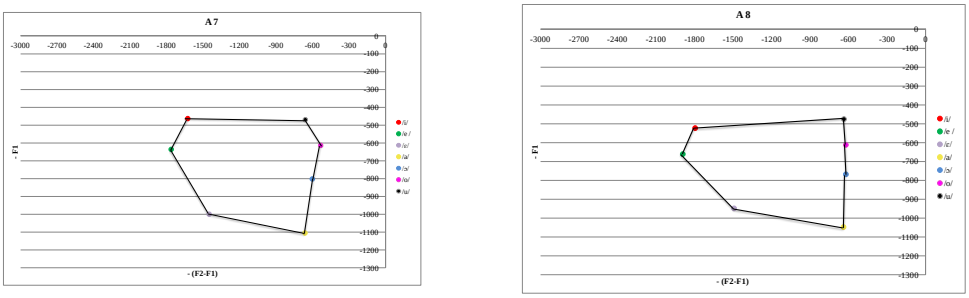

Figure 4: Graphical representation of Acoustic space of A7 and A8

Group A7 comprises of total 22 participant including 11 males and 11 females aged between 4Y5M to 4Y9M. There are 4 females and 3 males aged 4Y5M, 2 female and 3 males aged 4Y6M, 2 females and 4 male aged 4Y7M and; 3 female and 1 male aged 4Y8M. The participant in this age group have the lowest (F1) value as 462 Hz and highest as 1103 Hz. For (F2-F1) we find the lowest as 533 Hz and highest as 1762 Hz. Thus the range for (F1) is 641 Hz and for (F2-F1) the range is 1229Hz. Group A8 comprises of total 16 participant including 8 males and 8 females aged between 4Y9M to 5Y1M. There are 2 females and 3 males aged 4Y9M, 2 female and 2 males aged 4Y10M, 2 females and 3 male aged 4Y11M and; 2 female and 1 male aged 5Y0M. The participant in this age group have the lowest (F1) value as 474 Hz and highest as 1046 Hz. For (F2-F1) we find the lowest as 622 Hz and highest as 1892 Hz. Thus the range for (F1) is 572 Hz and for (F2-F1) the range is 1270Hz.

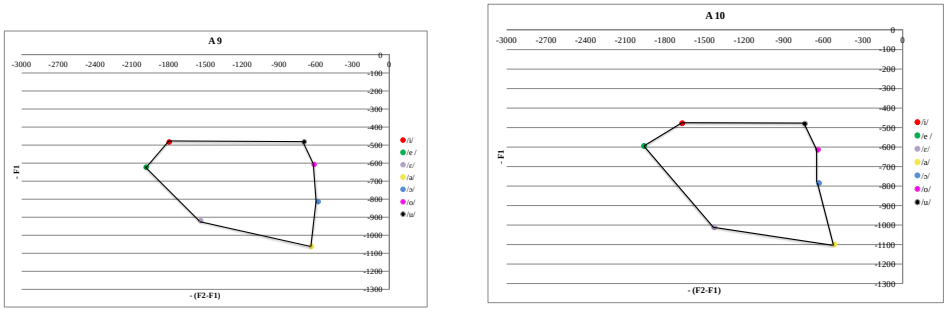

Figure 5: Graphical representation of Acoustic space of A9 and A10

Group A9 comprises of total 20 participant including 10 males and 10 females aged between 5Y1M to 5Y5M. There are 3 females and 2 males aged 5Y1M, 3 female and 3 males aged 5Y2M, 2 females and 3 male aged 5Y3M and; 2 female and 2 male aged 5Y4M. The participant in this age group have the lowest (F1) value as 481 Hz and highest as 1060 Hz. For (F2-F1) we find the lowest as 582 Hz and highest as 1985 Hz. Thus the range for (F1) is 579 Hz and for (F2-F1) the range is 1403Hz. Group A10 comprises of total 14 participant including 7 males and 7 females aged between 5Y5M to 5Y8M. There are1 female and 2 males aged 5Y5M, 2 female and 3 males aged 5Y6M and; 4 females and 2 male aged 5Y7M. The participant in this age group have the lowest (F1) value as 477 Hz and highest as 1098 Hz. For (F2-F1) we find the lowest as 517 Hz and highest as 1960 Hz. Thus the range for (F1) is 621 Hz and for (F2-F1) the range is 1443Hz.

Discussion

A comparison of acoustic space in terms of formant structures shows that the vowel height is already significant at 389 Hz which means that the vowels /i/-/u/ are in contrast with the open vowel /a/. The graph below shows the range of F1 (as vowel height) across different age groups:

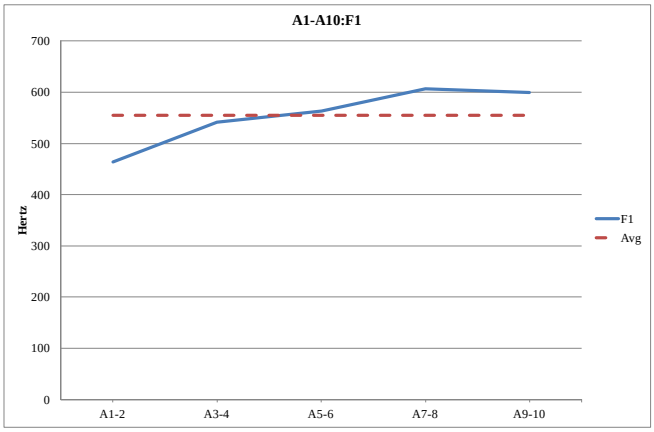

Figure 6: Range of F1 across A1- A10

The range across groups seems to be 555Hz and the youngest in the age group i.e. A1 is starting at 389 Hz i.e. approximately *-166* and the oldest age group i.e. A10 seems to be using the range for vowel height with *+85* i.e. 641 Hz as a variation. The youngest single child in -1 Group as discussed earlier is using 650Hz range already but with a very narrow front-back range of F2-F1. The oldest child at 5Y11M of age in Group 10+, is using a range of 440Hz which is lower than the average of 555Hz, perhaps because the child is also using a wide range for front-back distinction as indicated by F2-F1.

The acquisition of front-back contrast across groups as indicated by the range of F2-F1 is presented in the graphic representation below:

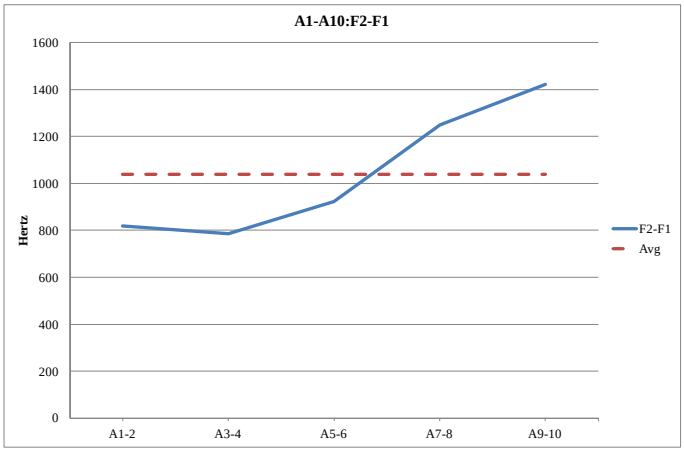

Figure 7: Range of F2-F1 across A1- A10

The graph represents the F2-F1 range across different age groups. The younger age groups A1-A2-A3-A4 (2Y5M-3Y9M) seem to be experimenting with the front-back vowel space till it stabilizes in A4 & A5. This implies that approximately from the age of 3Y9M of A4 Group there is a steady increase in the range of F2-F1, a steady development from approximately 700Hz to 1443Hz at the age of 5Y8M in A10.

If we compare both the graphs we find that the progression in F1 value is still stable. This means that the participants have the high-low contrast which is acquired already at the age of 2Y5M and remains steady at around 555Hz ±100 Hz. On the other hand, the progression in front-back contrast is steep and the progression is more.

It is also interesting to note that the F1 range keeps varying in these groups and stabilizes at 555 ± 100Hz for tongue height, whereas for F2-F1 the average range is 1039 Hz and is ±400 Hz for front-back. These findings definitely support the hypothesis that the vowel height is acquired earlier (even before 2Y5M) and the front back contrast is acquired relatively later as phonological acquisition progresses from 3Y5M right up to the age of 5Y5M, or longer.

Conclusion

The youngest child aged 2 Years 1 Month 5 Days was taken as group -1. The child at this age can already distinguish vowels by their height which is evident from F1. The distinction between high-low is quite prominent but the distinction between front-back is not as developed. Group 10+ consists of the oldest child aged 5 Years 11 Months and 15 Days. The range used by the child to contrast the front-back vowels and high-low are well defined as compared to the youngest child in group -1. The child at this age is able to maintain a front-back contrast in both the languages, Hindi and English. At this age the child is seen placing full concentration on front-back vowels rather than high-low vowels.

A comparison of 10 groups only on the basis of age was made. As mentioned earlier an equal number of male-female (80+80) participants were divided into different groups with a gap of 4

months from 2 years 5 months to 5 years 8 months old. Each group was numbered from A1, A2 to A10 keeping a gap of 4 months. Also, group -1 was designated to the youngest subject and group 10 + to the oldest. These two participants also served as a reference point to trace progression in acoustic characteristics of speech.

A comparison of acoustic space in terms of formant structures in the youngest age group aged 2Y5M to 2Y9M shows that the vowel height is already a significant 389 Hz which means that /i/-/u/ vowels are very much in contrast with the open vowel /a/. The overall F1 range across all groups is 555 Hz and the youngest in the age group i.e. A1 is starting at 389 Hz i.e. approximately -166 and the oldest age group i.e. A10 seems to be using the range for vowel height with +85 i.e. 641 Hz as variation.

The youngest single child in -1 group is using 650Hz range already but with a very narrow front-back range of F2-F1. The oldest child at 5Y11M of age in group 10+ is using a range of 440 Hz which is lower than the average of 555 Hz, perhaps because the child is also using a wide range for front-back distinction as indicated by F2-F1. It is also interesting to note that the F1 range keeps varying with ± 100 Hz in these groups and stabilizes at 555Hz for tongue height, whereas for F2-F1 the overall average range is 1039 Hz and varies with ± 400 Hz for front-back.

These findings definitely support the hypothesis that the vowel height is acquired earlier (even before 2Y5M) and the front back contrast is acquired relatively later as phonological acquisition progresses from 3Y5M right up to 5Y5M, may be longer. If we compare F1 and F2-F1 we find that the progression in F1 value is still stable. This means that the participants have the high-low contrast which is acquired already at the age of 2Y5M and remains steady at around 555Hz ±100 Hz. On the other hand the progression in front-back contrast is steep and the progression is more.

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APPENDIX

S.No	Group	Age Group	Male	Female	Total
1	*-1*	*2.01*	*0*	*1*	*1*
2	**A1**	2.05-2.09	5	5	**10**
3	**A2**	2.09-3.01	6	6	**12**
4	**A3**	3.01-3.05	7	7	**14**
5	**A4**	3.05-3.09	8	8	**16**
6	**A5**	3.09-4.01	8	8	**16**
7	**A6**	4.01-4.05	9	9	**18**
8	**A7**	4.05-4.09	11	11	**22**
9	**A8**	4.09-5.01	8	8	**16**

10	**A9**	5.01-5.05	10	10	**20**
11	**A10**	5.05-5.08	7	7	**14**
12	*10+*	*5.11*	*1*	*0*	*1*
	TOTAL		**80**	**80**	**160**

Table 1: Grouping A1 – A10

	Vowels	/i/	/e/	/ɛ/	/a/	/ɔ/	/o/	/u/
A1	**-F1**	-534.42	-706.5	-912.29	-1051.4	-775.01	-626.36	-523.13
	-(F2-F1)	-1279.8	-1283.2	-1190.4	-613.68	-690	-669.7	-710.08
A2	**-F1**	-486.69	-660.2	-903.01	-1014.28	-716.11	-593.25	-476.88
	-(F2-F1)	-1561.4	-1663.87	-1317.71	-720.69	-697.2	-708.64	-727.42
A3	**-F1**	-531.89	-657.04	-911.13	-1045.9	-776.18	-640.42	-516.57
	-(F2-F1)	-1504.1	-1475.6	-1208.5	-647.47	-632.7	-689.53	-724.42
A4	**-F1**	-513.28	-630.27	-883.5	-1067.9	-798.32	-624.86	-533.57
	-(F2-F1)	-1260.3	-1273.1	-972.7	-575.71	-610.7	-653.63	-635.79
A5	**-F1**	-527.56	-614.73	-965.9	-1060.8	-742.63	-627.96	-514.36
	-(F2-F1)	-1476.1	-1458.3	-1258.1	-612.24	-650.28	-654.84	-703.47
A6	**-F1**	-512.94	-668.57	-952.93	-1069.5	-780.55	-648.87	-488.68
	-(F2-F1)	-1571.1	-1560	-1292.3	-603.19	-627.07	-591.38	-697.98
A7	**-F1**	-462.29	-635.05	-998.21	-1103.8	-800.79	-612.75	-468.57
	-(F2-F1)	-1626.3	-1762.9	-1450	-662.41	-602.68	-533.95	-659.81
A8	**-F1**	-522.01	-660.03	-947.19	-1046.1	-766.82	-610.86	-474.49
	-(F2-F1)	-1796.4	-1893	-1493.4	-640.92	-622.74	-622.73	-637.57
A9	**-F1**	-482.07	-621.68	-917.13	-1060.8	-812.82	-606.54	-481.06
	-(F2-F1)	-1797.4	-1985.1	-1540.3	-636.26	-582.4	-615.43	-695.52
A10	**-F1**	-477.17	-593.41	-1009.8	-1098.1	-783.92	-612.65	-479.59
	-(F2-F1)	-1671	-1960.6	-1428.1	-517.98	-635.45	-643.04	-742.01

Table 2: Details of Group-wise Formants

Group	**F1**	**F2-F1**
A1	389	670
A2	538	966
A3	529	872
A4	554	698

A5	546	864
A6	581	980
A7	641	1229
A8	572	1270
A9	579	1403
A10	621	1443
Avg	**555**	**1039.5**

Table 3: Formant values and average of A1-A10

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