Research Article

A preliminary study of coarticulation in young Kannada speaking children: A locus equation perspective

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Key Words

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Abstract

This study aimed to determine the developmental patterns of coarticulation using F2 locus equation as a metric. Locus equations use the F2 transition to obtain regression lines by plotting onsets of F2 on the y-axis with the F2 midpoint on the x-axis for a given stop consonant across the various vowel contexts. In the present study, coarticulatory influence of vowel /a/ over voiced stops in different places of articulation [b], [d], [d] and [g] was studied. The participants were native Kannada speakers, 15 children each in the age groups of 4-5 years and 5-6 years. Participants were asked to produce non words in CVCV pattern embedded in a carrier phrase. The recorded utterances were subjected to acoustical analysis using PRAAT software (Version 5.1.14). In $C_1V_1C_2V_2$ form of stimuli, V_1 was the target vowel. The measured F2 values were subjected to regression analysis by considering F2 vowel midpoint as the independent variable and F2 vowel onset as the dependent variable. Extraction of slope values from linear regression revealed higher coarticulation in the younger group as compared to the older group supporting the holistic theory of coarticulation.

Introduction

According to Kuhnert & Nolan (1999), "coarticulation in a broad manner refers to the fact that a phonological segment is not realized identically in all environments, but often apparently varies to become more like an adjacent or nearby segment." For instance, the English phoneme /k/, will be produced with the tongue in a relatively forward position when accompanied with front vowels ([ki] *key*) and comparatively backward in the context of a back vowel ([ka] *caw*). Variations such as this have been traditionally thought of as allophonic variation (Everett, 2008). Coarticulation also refers to events in speech where the vocal tract shows immediate changes which approximate for the production of different sounds at a given time.

Children at different stages of their speech and language development tend to employ coarticulation in different ways. From babbling to learning complex patterns of connected speech, the child skilfully articulates, a plethora of sound combinations, using necessary coarticulatory adjustments to accommodate neighbouring sounds. Variability in coarticulation in children can be explained by the following two theories:

1. Children tend to produce speech rather more segmentally than adults. This is thought to reflect an acquisition process wherein the physical act of temporal sound sequencing is achieved prior to acquisition of finer details of temporal co-ordination of the articulators develop later. Consequently, co-articulation is possibly less pronounced for young children. This is the **segmental theory** (Kent, 1983)

2. **Holistic theory** suggests that childrens' productions might be characterized by more, rather than less co-articulation (Nittrouer & McGowan, 1989). Here children are assumed to rely largely on syllable-based speech production units and then gradually narrow their minimal domain of articulatory organization. Thus, the spatio-temporal overlap of articulatory gestures is more predominant during the early years and then gradually subsides through a process of differentiation. This theory predicts greater anticipatory coarticulationin children's speech than in adults' coarticulationpatterns as is reflected in their babbling (Nittrouer et al., 1996).

Perceptual, physiological and acoustic modes of analyses of coarticulation have been predominantly documented in literature. For investigating coarticulation in disordered population, researchers tend to choose relatively more indirect techniques such as acoustic analysis, because of the limitations in other modes of analyses. Though acoustic analy-

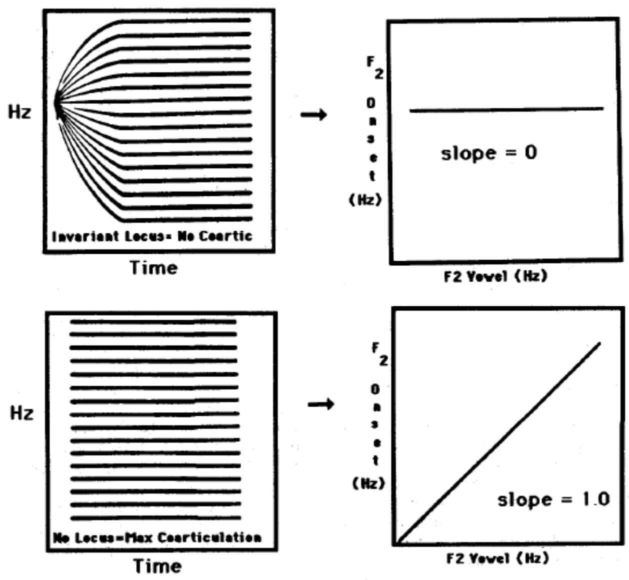

Figure 1: Hypothetical extremes of locus equation slopes. The upper panel illustrates a situation that would occur with an invariant consonantal locus when no coarticulation is present between consonant and vowel. The lower panel reflects a condition of no consonantal locus and maximum coarticulation between consonant and vowel (Sussman et. al., 1996).

sis solely cannot furnish exact quantitative information about various articulatory parameters, the transition between the consonant and vowel will provide an insight into the dynamics of coarticulation. In order to examine coarticu^{l}atory effects of stop consonants on vowels, locus equations have been predominantly used and this concept was first described by Lindblom (1963), and studied most extensively by Sussman et al. (1991).

According to Sussman et al. (1991), "locus equations are linear regressions of the frequency of the second formant transition sampled at its onset (F2 onset) on the frequency of the second formant sampled in the middle of the following vowel (F2 midpoint) for a single consonant co articulated with a range of vowels." The F2 onset is plotted on the y axis and the F2 vowel on the x axis. In short, locus equations representing a particular consonant can be represent by the equation $F2_{onset} = k \times F2_{vowel} + c$ where k and c are the constants, slope and y-intercept respectively.

Locus equations represent the F2 onset of a given vowel as a function of the F2 for the midpoint of a given vowel. That is, the F2 onset value corresponding to the release of a particular stop consonant is observed to co vary with the target F2 of the following vowel. For this reason, locus equations are found to be useful in studying the extent to which place of articulation of particular stops can be influenced by the positioning of the tongue during the production of following vowels.

Considerable research has proved the fact that F2 onset values are accurate predictors of place of articulation of consonants appearing before the sampled vowel (Liberman et al., 1954). Krull (1987) proposed that the locus equation slope quantified the extent to which the imminent vowel affected the frequency onset of the F2 transition. The locus equation slopes were shown to range from 0 to 1. Flatter slopes characterise those stops that are relatively resistant to co-articulatory effects regardless of the following vowel. Flatter slopes (closer to 0.0) occur when F2 onsets following a particular consonant are relatively fixed and are not greatly influenced by the F2 of the following vowel's (Fig.1, upper panel). Conversely, more positive locus equation slopes (closer to 1.0) are indicative of greater degrees of coarticulation between a stop and the vowels that follow the stop. (Fig. 2, lower panel).

Method

Participants: The participants were native Kannada speakers, 15 children each in the age groups of 4-5 years and 5-6 years. The sample included both boys and girls. It was ensured that the participants did not have any medical, speech, language, hearing, cognitive or any other motor difficulties.

Stimuli: The stimuli were of the form $C_1V_1C_2V_2$ where C_1 and C_2 were voiced stops such as bilabial /b/, dental /d̪/, retroflex /d̥/ and velar /g/ in conjunction with low central vowel /a/ (V_1 and V_2). Hence the target utterances were /baba/, /d̪ad̪a/, /d̥ad̥a/ and /gaga/. These stimuli were embedded in the carrier phrase /na:nu i:ga ***"CVCV"*** anta h:elthini/ (Now I will say ***CVCV***). The material

Table 1: Shows regression analysis related parameters for voiced stops across various places of articulation for children aged 4-5 years and 5-6 years

Age group	Voiced Stop	R^2	SE (Hz)	Slope	y-intercept (Hz)
4-5 years	/ba/	0.743	107	1.3	-679
	/d̪a/	0.659	104	1.19	-167
	/d̥a/	0.440	130	0.77	770
	/ga/	0.708	91	0.81	402
5-6 years	/ba/	0.404	63	0.56	654
	/d̪a/	0.150	113	0.33	1501
	/d̥a/	0.041	100	0.21	1809
	/ga/	0.388	78	0.58	788

included only voiced stop consonants for the ease to mark the first glottal pulse during the F2 locus analysis (Krull, 1987).

Procedure: Stimuli were elicited from each participant using "repeat after me" procedure. Three repetitions were elicited from each participant. Utterances were recorded using a digital recorder (LS 100 Olympus Multi track linear PCM recorder) with sampling frequency of 44000 Hz.

Analyses: The recorded data from the digital recorder were transferred on to a computer and analyzed for extracting spectral features using PRAAT software (Version 5.1.14). Locus equation requires onset and midpoint of F2 vowel. F2 is considered to be a significant cue for place of articulation. F2 vowel onset and midpoint of V1 of each $C_1V_1C_2V_2$ utterance were measured. Vowel onset was identified as the onset of voicing in the second formant of the vowel subsequent to the consonant release. Following Sussman et al. (1991), in cases of U- or inverted U shaped formant patterns, the midpoint was considered to be the value at the trough or peak. In case of steady changes in frequency, the formant value at the mid of the vowel was selected. Using SPSS (Ver. 21), scattergrams were used to plot the data by treating F2 onset as a dependent variable and F2 midpoint as an independent variable for each consonantal place of articulation category. Thus, slope, y-intercept, Standard error of Estimate (SE) and R^2 functions from 8 regression scatter-plots were calculated for the participants across the four places of articulation (2 groups × 4 tokens). The slope function described degree of coarticulation for each place of articulation for each age group. The y-intercept together with the slope more fully captures an acoustic representation of place of articulation. The SE described goodness of fit around the regression line, and the R^2 described the extent of variability of F2 onset with the F2-vowel midpoint.

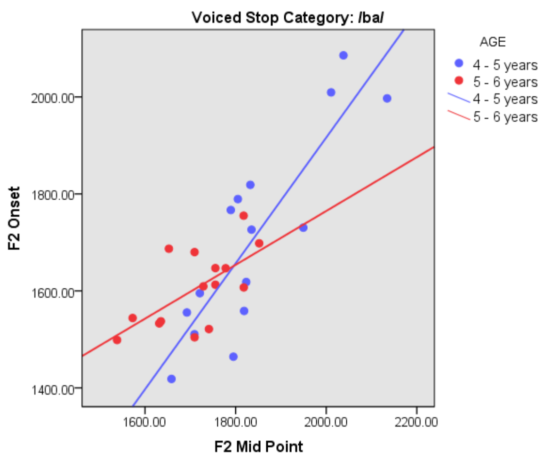

Figure 2: Locus equation scatter-plot for dental /d̪a/
Locus equation for 4-5 years:
F2 onset =1.19x F2 vowel - 167; R^2=0.659
Locus equation for 5-6 years:
F2 onset = 0.33xF2 vowel + 1501 ; R^2= 0.15

Results

Slope and y-intercept: Slope values revealed a specific trend for place of articulation across voiced stop place of articulation in children aged 4-5 years and 5-6 years. It was observed that, the overall mean slopes for the age group 4-5 years for /ba/, /d̪a/, /d̥a/ and /ga/ were 1.3, 1.19, 0.77 and 0.81 respectively whereas the slope values for the older age group of 5-6 years were 0.56, 0.33, 0.21 and 0.58 respectively. Y-intercept values for the younger group for /ba/, /d̪a/, /d̥a/ and /ga/ were -679 Hz, -167 Hz, 770 Hz and 402 Hz respectively and were 654 Hz, 1501 Hz, 1809 Hz and 788 Hz for the older group. Thus, the extent of coarticulation in the first age group was of the order: /ba/> /d̪a/> /ga/>/ /d̥a/ while in the older group, it was /ga/>/ba/>/d̪a/>/d̥a/ here. R^2values were generally higher in the younger age group (4-5 years), indicating a fairly higher extent of coarticulation as compared to the older group. It was observed that the regression model was a significant fit for

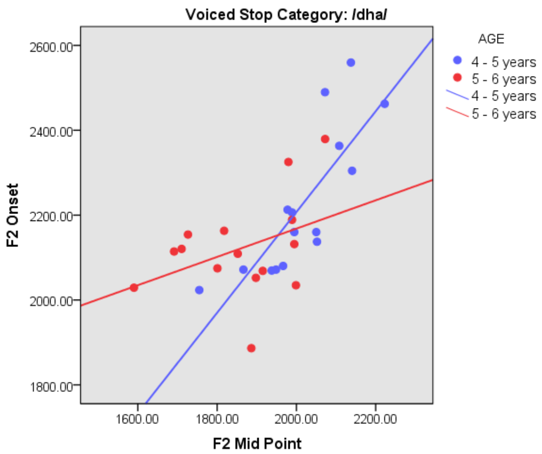

Figure 3: Locus equation scatter-plot for dental /d̪a/
Locus equation for 4-5 years:
F2 onset =1.19x F2 vowel - 167; R^2=0.659
Locus equation for 5-6 years:
F2 onset = 0.33xF2 vowel + 1501 ; R^2= 0.15

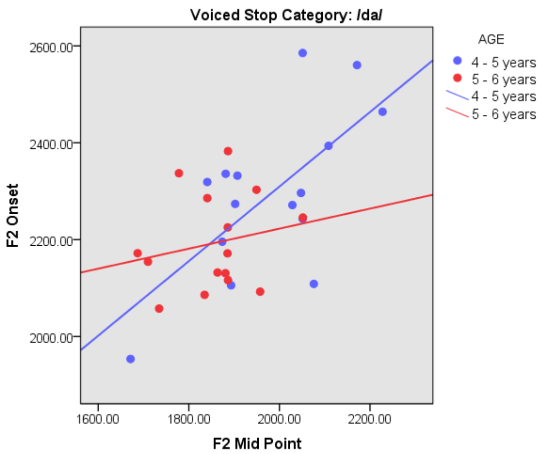

Figure 4: Locus equation scatter-plot for velar /ga/
Locus equation for 4-5 years:
F2 onset =0.77x F2 vowel +770; R2=0.440
Locus equation for 5-6 years:
F2 onset = 0.21xF2 vowel + 1809 ; R2= 0.041

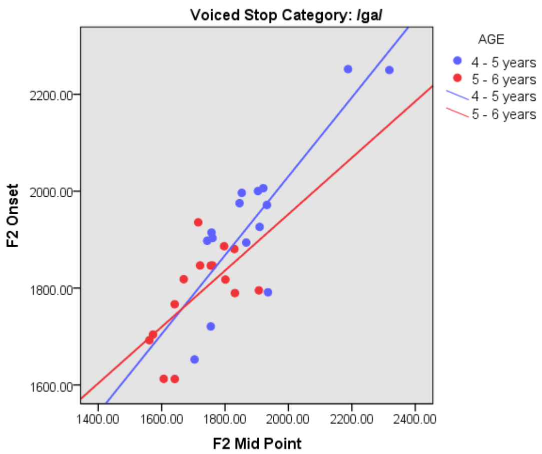

Figure 5: Locus equation scatter-plot for alveolar /d̥a/
Locus equation for 4-5 years:
F2 onset =0.81x F2 vowel + 402; R^2=0.708
Locus equation for 5-6 years:
F2 onset = 0.58xF2 vowel + 788 ; R^2= 388

all stop categories ($p<0.05$). However, in children aged 5-6 years, the regression models were significant fits for stops /ba/ and /ga/ ($p<0.05$) and were not significant for /d̪a/ and /d̥a/ ($p>0.05$). Table 1 represents the slope, y-intercept, R^2 and SE for different voiced stops across age groups of 4-5 years and 5-6 years. Figures 1-4 show slopes in 4 and 5 year old children with respect to various voiced stop categories: bilabial /ba/, dental/d̪a/, retroflex /d̥a/ and velar /ga/.

Discussion

The locus equation metric was used to examine coarticulation patterns in voiced stop CV productions in children of age 4-6 years. Although it is not possible to derive any conclusions about general developmental trends from this limited data, they may serve as a ground work for formulating certain conclusions about the development of anticipatory coarticulation. Children in the present study produced /d̥a/ with least coarticulation which can evidenced by relatively lesser slope value and higher standard error values (130 Hz in 4year olds and 100 Hz in 5 year olds). Thus, the alveolar stop /d̥a/ was produced with the flattest slope. Similar findings have been reported by Sussman et al. (1992) who studied coarticulation in 16 children aged 3-5 years. Mc Leod et al. (2001) also reported similar findings in adult speakers. This finding confirms that of Sussman et al. (1991) that locus equation slopes serve effectively as place of articulation descriptors.

Another salient feature observed in the study was, children in the older group produced stop consonants with comparatively lower slope values and lower regression coefficients as compared to the younger children. Moreover, the greater extent of overlap in bilabial and dental functions in the younger group (4-5 years) and lesser extent in the older group (5-6 years) suggested that the younger children were probably in the process of tuning their coarticulatory dynamics to achieve maximal contrast of stop place categories. Older children were capable of producing utterances more distinctly without much articulatory tweaking. Similar findings by Sussman et al. (1992) ascertain the findings of the present study.

Conclusions

The present study aimed to delineate the developmental trends in coarticulation in native Kannada speaking children aged 4-6 years. Based on regression analysis, it can be inferred that coarticulatory extent in voiced stop place of articulation was of the order /ba/> /d̪a/>/ga/> /d̥a/ in younger children (4-5 years) and of the order

/ga/> /ba/>/d̪a/>/ḍa/ in older childen. Greater slope and R^2 values in the younger children implied greater extent of coarticulated speech in them which supports the holistic theory of coarticulation. (Nittrouer et al, 1996). Understanding the task of producing contrastive and acoustic categorisations will help transfer attention to the generation of the signal and the underlying speech motor skills that produce it. This knowledge can be of worth in teaching speech production skills to children having various communication disorders.

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