DEVELOPMENTAL OF ANTICIPATORY COARTICULATION OF /u/ IN MALAYALAM SPEAKING CHILDREN

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MANASAGANGOTHRI, MYSORE – 570 006

MAY, 2014

CERTIFICATE

This is to certify that this dissertation entitled "**Development of Anticipatory Coarticulation of /u/ in Malayalam speaking children**" is a bonafide work submitted in part fulfilment for the Degree of Master of Science (Speech Language Pathology) of the student (Registration No: 12SLP013). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any of the University for the Award of any other Diploma or Degree.

Mysore

May, 2014

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CERTIFICATE

This is to certify that this dissertation entitled "**Development of Anticipatory Coarticulation of /u/ in Malayalam speaking children**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**Development of Anticipatory Coarticulation of /u/ in Malayalam speaking children**" is the result of my own study under the guidance of Dr. S. R. Savithri, Director, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

Mysore Register No.: 12SLP013

May, 2014

DEDICATED TO PAPPA, MUMMY

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SAVITHRI MA'AM

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CHAPTER I

INTRODUCTION

"Coarticulation in broader 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" (Kuhnert & Nolan, 2000). "Coarticulation describes the concept that the articulators are continually moving into position for other segments over a stretch of speech" (Flecher, 1992).Physiologically coarticulation is the simultaneous movement of two articulators. Acoustically it is the overlapping acoustic property of one phoneme to another. Perceptually it is a phoneme perceived in anticipation/ after another phoneme. During the production of conversational speech, the acoustic features of individual sounds get blended together into a particular type of acoustic code which allows the speaker's message to efficiently transmit to the listener. Even though the muscle movement of the individual articulators is relatively slow, the parallel nature of their movement allows information about successive sounds to be encoded simultaneously in the acoustic signal (Liberman, Mattingly, and Turvey, 1972). Thus, each sound we produce often affects those which both follow and precede it (Mullin, Gerace, Mestre, and Velleman, 2003). This phenomenon of the individual speech sounds which mingles with those of its adjacent sound can be in mainly in two directions, forward or anticipatory and perseveratory or carryover coarticulation. Forward or anticipatory coarticulation occurs when a sound or phoneme is affected by the production characteristics of its subsequent sound. For E.g., while producing the sounds /su/ and /si/, the production /s/ is affected by the production of/u/. The lip rounding for /u/ takes place much before the production of the /s/ sound. This effect of /u/ on /s/ is referred to as anticipatory coarticulation. When a latter sound is modified due to the production of an earlier sound, this is referred as Perseveratory (or carryover) coarticulation. Abelin, Landberg and Persson (1980) reported that adults adopt a look-ahead strategy while the children's labial coarticulation appeared to be time-locked, i.e. the temporal extent of anticipation became more prominent with age. There are some studies which supports that the coarticulation is more inyoung children than that of adults (Nittrouer, Studdert-Kennedy & McGowan, 1989; Nittrouer, Studdert-Kennedy, & Neely, 1996; Nittrouer & Whalen, 1989), a second set of studies report that children exhibit less coarticulation than adults (Hodge, 1989; Repp, 1986; Sereno & Lieberman, 1987). Again a third set of findings reveals similar patterns of coarticulation in the speech of children and adults, but greater variability of coarticulatory patterns are exhibited by children than those of adults (Goodell & Studdert-Kennedy, 1993; Katz & Bharadwja, 2001; Katz, Kripke, & Tallal, 1991; Nittrouer, 1993; Sereno, Baum, Marean, & Lieberman, 1987; Sharkey & Folkins, 1985; Sussman, Duder, Dalston, & Cacciatore, 1999; Turnbaugh, Hoffman, & Daniloff, 1985).

Three studies support the view that coarticulation is more in young children compared to adults. Nittrouer et al (1989) conducted a study on the anticipatory and perseveratory coarticulation of the vowels /i/ and /u/ across two different fricative contexts (/ʃ/ and /s). Study included 40 subjects (8 children and 8 adults in the each of the ages 3, 4, 5, 7 and all adults were 20 or 21 years of old). Targets were 4 nonsense bisyllables (/sisi/, /susu/, /ʃiʃi/, /ʃuʃu/). It was found that the extent of differentiation between /s/ and /ʃ/ increased with age but coarticulation for fricatives with its following vowel was reported to be decreased with age. A follow up study on the earlier work of Nittrouer et al. (1989) was carried out by Nittrouer & Whalen (1989) with similar material and conditions and it was found that enhanced coarticulatory effects seem to provide additional perceptual information that significantly improves the accurate identification of the syllable. Nittrouer et al (1996) conducted a study were the F2 frequencies were measured on fifteen consonant-vowel syllables consisting of the consonants /s/, /ʃ/, /t/, /k/, and /d/ and of the vowels /a/, /i/, and /u/ produced in a carrier phrase. 40 speakers (10 children each of the ages of 3, 5, 7 years, and 10 adults of ages from 20 to 40 years) served as participants of the study. The target schwa was found to be differentially affected by the production of the subsequent consonant and vowel phoneme in all groups of subjects. However, the coarticulation between the schwa and the subsequent phonemes was more pronounced in children's speech than in adult subjects. The authors concluded that the age-related differences in anticipatory coarticulation could not be fully explained by morphological differences in vocal tract anatomy. Study supported the Nittrouer et al's (1989) results showing children having greater effects than adults of the upcoming vowel on F2 frequencies.

Some studies support the view that children exhibit less coarticulation than adults. Repp (1986) conducted a study on speech production of 2 children in the age of 4.8years and 9.8 years and an adult. Children were Native American English speakers and adult Native German speaker who mostly speaks English. He examined the coarticulation of an unstressed schwa preceding a consonant-vowel context. The target schwa preceded the syllables /si/, /sɑ/, /su/, /ti/, /tɑ/, and /tu/, it was embedded in the carrier phrase *I like the* _______. Results revealed that a 4-year-old speaker did not display systematic differences in their schwa production across the different linguistic contexts, whereas a 9-year-old and adult speaker did exhibit such differences. The interpretation made from the study should be taken with caution due to the limited number of participants.

Sereno and Lieberman (1987) also found less evidence of coarticulation in children when compared to adults; they conducted a perceptual study in which ten speakers listened to the initial 25 ms of the syllable as spoken by the test subjects. The study included children in the age range of 2 to 7 years and a comparison group of adults. This study examined the effect of the vocalic context on a preceding /k/ phoneme in the syllables /ki/ and /kɑ/. Results indicated that the adults exhibited consistent patterns of anticipatory lingual coarticulation, but for the children however variation in coarticulation was noted. The authors suggest that consistent coarticulatory patterns emerge with the acquisition of the fine-tuned speech motor patterns that accompany maturation.

Some other studies explain that children and adults are having similar patterns of coarticulation. Katz et al. (1991) studied both lingual and labial anticipatory coarticulation in a group of 3, 5, and 8year olds and adults. Results indicated that for a /s/ followed by a vowel (/sV/), acoustic measures did not differ as a function of age, which contradicted earlier research by Nittrouer et al. (1989). Authors again found that the magnitude of lingual coarticulation was quite similar for all subjects, both children and adults. This study examined the effect of the vocalic context on a preceding /s/ phoneme in the syllables /si/ and /su/, produced in the carrier phrase *I said* ____. The researchers found no evidence that suggested a greater degree of coarticulation in 3-year-old speakers as compared to older speakers, also the acoustic and video data supported the notion that 3-year-old children coarticulate speech sounds in a manner that is very similar to older children and adults. This conclusion was in support of finding of other researchers (e.g. Sereno et al., 1987; Sharkey & Folkins, 1985; Turnbaugh et al., 1985).

Majority of research in the field of children's coarticulation has commonly involved children 3 years of age or older. However, Goodell and Studdert-Kennedy (1993) designed a study that examined the speech behavior of children as young as 20 months of age. This study also differed from other studies in that it was a longitudinal examination of the maturation of speech production of the child participants across a 10-month time period. The participants of the study were all in the early stages of speech development, ranging in age from 22 to 37 months. The study examined coarticulation of an unstressed schwa in a variety of consonant and vowel contexts. Specifically, the authors investigated the first and second formant frequency patterns of the schwa when embedded in the following nonsense syllables: /bə'bɑ/, /bə'bi/, /bə'dɑ/, /bə'di/, /bə'gɑ/, and /bə'gi/. The researchers found clear differences in duration and coordination of gestures between adults and these relatively young children, as well as a clear shift toward adult-like patterns at about age 3 years. In addition, Goodell and Studdert-Kennedy found that details regarding child-adult differences and developmental changes vary from one aspect of an utterance to another, indicating that intra-subject variation in children may account for much of the discrepancy among previous researchers' findings.

Nittrouer (1993) found that children's tongue gestures are constrained by phonetic context more than those of adults until at least 7 years of age, this study also examined coarticulation by looking at the acoustic characteristics of an unstressed schwa when followed by different consonant-vowel syllables, created by combining the consonants /s/, /ʃ/, /t/, /k/, and /d/ with the vowels /i/, /ɑ/, and /u/. According to the author, the children participating in the study were able to acquire adult-like patterns of jaw movements sooner than they did for tongue movements. In addition, although the children produced gestures similar in shape to those of the adults, many of these speech movements were produced more slowly and with greater temporal variability. In light of these results, the author also concluded that the contradictions in various research findings might arise from differences in test tokens and methods of analysis. Boucher, 2007 investigate anticipatory coarticulation in typically developing young children between the ages of three and six years. This study focuses on the acoustic characteristics of an unstressed vowel, the schwa, and prior to a series of real words. Results indicate that children exhibit adult-like patterns of coarticulation even at a relatively young age. However, the degree of anticipatory coarticulation is dependent upon the phonemic context, with greater differences being evident in a fricative context and less when followed by a stop consonant.

Sussman et al. (1999) conducted a longitudinal study of a child speaker from age 7 months to age 40 months. This study was meant to investigate the earliest developments of coarticulation from babbling through the acquisition of early words, and eventually into segments of running speech. As elicitation of target syllables would prove difficult in infants, the authors extracted (from running speech samples) utterances containing /bV/, /dV/, and /gV/ syllable combinations. The researchers found that for labial sounds in a consonant-vowel context, the participant exhibited a steady increase in coarticulation with chronological maturation. The authors concluded that the child's speech had adult-like patterns of coarticulation by approximately 10 months of age. Results of the study indicate that children develop adult-like patterns of coarticulation for alveolar stops in the prelinguistic babbling stage (7 months of age) and for velar stops by the end of the first year.

Studies have also reported that coarticulation in children varies according to consonant type. Katz and Bharadwaj (2001) state that there are many problems associated with measuring articulatory movement patterns using solely acoustic data. Thus, the researchers chose to examine coarticulatory patterns in kinematic (electromagnetic articulography) and perceptual terms, comparing productions of /sV/ and /ʃV/ in children 4 to 7 years of age. Both kinematic and (preliminary) perceptual data revealed more lingual coarticulation in children for /sV/ than for /ʃV/.

Zharkova, Hewlett, Hardcastle (2008) had done a study on lingual coarticulation. The participants were four adults and four normally developing children aged 6 to 9 years, all speakers of Standard Scottish English. The data were the syllables /_i/, /_u/ and /_a/, in the carrier phrase "It's a … Pam" (ten repetitions). Synchronised ultrasound and acoustic data were recorded using the Queen Margaret University ultrasound system. Extent of consonantal coarticulation and within-speaker variation in child and adult productions were compared according to a new ultrasound-based measure of coarticulation. A significantly greater amount of anticipatory lingual coarticulation was found in children than in adults. Much within-group variability was observed, in both age groups. Within-speaker variability was significantly greater in children than in adults. These results are in agreement with some previous studies. Possible reasons are discussed for some of the contradictions in the literature on child and adult coarticulation.

It is interesting to note that some phonemes impose high coarticulation effect (e.g. /u/) and some do not. Kozhenikov and Chistovich(1965) found that lip rounding for /u/ can start at the beginning of a CCV (consonant – consonant – vowel) syllable, if none of the intervening sounds requires a movement that is antagonistic to it. Ohman (1966) has postulated, from spectrographic evidence that the tongue moves from vowel shape to vowel shape with articulatory gestures for the consonants superimposed on those of the vowels. Daniloff and Moll (1968) found that the lips begin to round for /u/ several phones before the vowel. Bell - Berti and Harris (1979) found orbicularis oris muscle activity for the /u/ at a relatively fixed time before the vowel sound, during the activity for the consonant or consonant cluster preceding it but unaffected by the number of consonants intervening (Raphael, Borden and Harris, 2011)./u/ is a high back vowel which is articulated with the dorsum of the tongue raised toward the roof of the mouth near the juncture between the hard palate and the velum. This is accomplished by contracting the styloglossus muscle which is innervated by hypoglossal (twelfth cranial) nerve. Speakers also round and protrude their lips by contracting the orbicularis oris muscle which is innervated by the facial (seventh cranial) nerve. "The acoustic effect of this positioning of the lips and tongue is threefold: First, the protrusion of lips increases the overall length of the vocal tract and thus lowers the frequencies of all formants. Second, the raising of tongue dorsum pulls the bulk of the tongue out of the pharyngeal cavity, enlarging it and allowing it to resonate to the low – frequency harmonics composing the first formant of this vowel. Third, the posterior constriction formed by the raised tongue dorsum and the protrusion of the lips lengthen the oral cavity, allowing it to resonate to the relatively low – frequency harmonics that make up the second formant of /u/" (Raphael, Borden & Harris, 2011).

Lubker & Gay, 1981, did a study to resolve the differences between two views of anticipatory labial coarticulation. One of these views contends that a speaker begins labial movement toward a rounded vowel in direct relation to the amount of time available while the other view posits an onset of movement that is temporally locked to the rounded vowel. Participants were 4 normal adult American English speakers and 6 normal adults who were native speakers of Swedish. Electromyographic signals were sampled from four muscles associated with labial movement while, simultaneously movements of the upper lip in the anterior-posterior and vertical dimensions were recorded. Material used included both meaningful disyllabic words of each language and non sense disyllabic words. Results suggested that there are a number of purely biological and experimental variables which can intrude upon research of this type, and there are also language-specific differences in the production of rounded vowels which suggest that Swedish and American English speakers have learned different motor-programming goals.

Perumal (1993) investigated the development of production of coarticulation in 4 – 7 year native kannada speaking children. Six age groups were present with 6 months of interval and 10 children each in each group. Consonants /p/, /t/, /k/ and vowels /a/, /i/, /u/ served as the materials for the study. Results indicated no linear development for coarticulation. It was found that there was an increase in transition duration by the age of 7 years and terminal frequency decreased by the age of 7 years.

The review indicates that coarticulation and its development is language dependent and also variations can be seen in both adults and children. Malayalam [Malayalam is a language spoken in India, predominantly in the state of Kerala. It is one of the 22 scheduled languages of India and was designated a Classical Language in India in 2013. Malayalam has official language status in the state of Kerala and in the union territories of Lakshadweep and Puducherry. It belongs to the Dravidian family of languages, and is spoken by approximately 33 million people according to the 2001 census - http://en.wikipedia.org/wiki/Malayalam] as a Dravidian language has extra lip rounding and nasality as its typical feature. The consonant system of Malayalam exhibits a rare five place of articulation contrast in stops and nasals (Mohanan and Mohanan, 1984); where as English has three places of articulation for stops and nasals. Therefore, the development of coarticulation guided by extra lip rounding, may be different in Malayalam compared to other languages.. In this context, the present study investigated the development of anticipatory coarticulation of /u/ in Malayalam speaking children in the age range of 3–6 years. The objectives of the study were (a) to measure transition duration of F_2, (b) terminal frequency of F_2, and (c) extent and speed of transition of F_2 in vowel /u/ when preceded by various consonants in typically developing Malayalam speaking children. The knowledge about the development of coarticulation will enhance our understanding of coarticulatory development and the information obtained from this study can be used for high quality synthesis of children's speech. Further, an understanding of the development of coarticulation in typically developing children will help in diagnosis and rehabilitation of disordered population.

CHAPTER II

REVIEW OF LITERATURE

"Coarticulation in its general sense refers to a situation in which a conceptually isolated speech sound is influenced by, and becomes more like, a preceding or following speech sound" (Terry, 1997). According to Oxford Dictionary Oxford Dictionary the articulation of two or more speech sounds together, so that one influences the other: *Allophones can occur as a result of coarticulation across word boundaries.*

"Coarticulation is the way the brain organizes sequences of vowels and consonants, interweaving the individual movements necessary for each into one smooth whole. In fact, the process applies to all body movement, not just speech, and is part of how homo sapiens works. It takes about a fifth of a second to produce a syllable, or about a fifteenth or twentieth of a second for each consonant or vowel. It takes a little longer than that to move the lips, tongue and jaw for each vowel and consonant. The brain coordinates these individual articulator movements in a very ingenious way, such that movements needed for adjacent vowels and consonants are produced simultaneously. This results in speech being produced very smoothly. At the same time it spreads out acoustic information about a vowel or consonant and helps a listener understand what is being said. Speech coarticulation is thus also a very important part of the special code that enables us to speak at five syllables a second. For example, suppose you say the word /ˈhæpi/. Before you say anything, you will start breathing out, and you will have moved your tongue into position for/æ/ and started opening your mouth for /æ/. Then, while you are hissing for /h/, it will sound a bit like a whispered /æ/, When you stop hissing for /h/, you will turn your voice on for /æ/. When you start saying /æ/, you will continue opening your mouth for /æ/. Once your mouth is fully open for /æ/, you will start closing it again, and your lips, for /pp/. As your lips meet, you will switch your voice off for /pp/. While your lips are together for /pp/, you will be moving your tongue from where you had it for a towards where you need it for y. As you separate your lips from /pp/, you will let a tiny puff of air escape between them. As the puff ends you will turn your voice on for y. While you start saying y, you will continue to move your tongue to where you need it for y and continue opening your lips after /pp/. Once your tongue is in position for /i/, you will keep it there. Once your done with y you will switch your voice off, move your tongue away from /i/, and start breathing in. The whole word will usually be uttered in less than half a second. The precise timings might differ collectively between different accents. Some people might have their own individual timings, part of what makes you sound just you" (http:// swphonetics.com/ coarticulation/whatcoart/).

"Coarticulation in phonetics refers to two different phenomena. The assimilation of the place of articulation of one speech sound to that of an adjacent speech sound. For example, while the sound/n/ of English normally has an alveolar place of articulation, in the word *tenth* it is pronounced with a dental place of articulation because the following sound, /θ/, is dental. the production of a co-articulated consonant, that is, a consonant with two simultaneous places of articulation. An example of such a sound is the voiceless labial-velar plosive /k͡p/ found in many West African languages" (Terry, 1997).

The term coarticulation also refers to the transition from one articulatory gesture to another (Terry, 1997).

Physiologically coarticulation is the simultaneous movement of two articulators. Acoustically it is the overlapping acoustic property of one phoneme to another. Perceptually it is a phoneme perceived in anticipation/ after another phoneme. There are two types of coarticulation. *Anticipatory coarticulation* - when a feature or characteristic of a speech sound is anticipated (assumed) during the production of a preceding speech sound - and *carryover or perseverative coarticulation* - when the effects of a sound are seen during the production of sound(s) that follow.

Several models - *look-ahead, articulatory syllable, time-locked, window, coproduction and articulatory phonology* - have been developed to account for coarticulation.

Kozhevnikov and Chistovich propose the ***articulatory syllable*** and state that speech is organized in articulatory syllables and the syllable boundary provides a limit on anticipatory coarticulation. Henke (1967) proposes the ***look-ahead*** model in which he believes that the speech units are organized as bundles of independent parallel articulatory feaatures. Ther is no restriction on the initiation of a featute of segment except that it can not be antagonistic to the intervening segment. Therefore, the syllable boundary has no particular status and should not inhibit coarticulation.

According to Lieberman, Cooper, Shankweiler and Studdert-Kennedy (1967) coarticulation as an evolutionary development that probably had emerged in response to a implicit demand for a more rapid rate of communication. Without coarticulation, one would be speaking no faster than one can spell. In his view, “coarticulation is what makes the high rates of phonemes per second possible. In parallel, auditory perception – allegedly not capable of handling such high rates –, co-evolved with production and came to include a phonetic module specialized for speech perception and for decoding coarticulated signals" (Lieberman et al, 1967). A similar view has been expressed by Lieberman (1991).

Lindblom & MacNeilage (2011) instead of than viewing coarticulation as an innovation for increasing transmission rate, prefer to trace the roots of this process to how speech motor control has been shaped, step by step, by building on existing mechanisms.

There are some studies which supports that the coarticulation is more in young children than that of adults (Nittrouer, Studdert-Kennedy & McGowan, 1989; Nittrouer, Studdert-Kennedy, & Neely, 1996; Nittrouer & Whalen, 1989), a second set of studies report that children exhibit less coarticulation than adults (Hodge, 1989; Repp, 1986; Sereno & Lieberman, 1987). Again a third set of findings reveals similar patterns of coarticulation in the speech of children and adults, but greater variability of coarticulatory patterns are exhibited by children than those of adults (Goodell & Studdert-Kennedy, 1993; Katz & Bharadwja, 2001; Katz, Kripke, & Tallal, 1991; Nittrouer, 1993; Sereno, Baum, Marean, & Lieberman, 1987; Sharkey & Folkins, 1985; Sussman, Duder, Dalston, & Cacciatore, 1999; Turnbaugh, Hoffman, & Daniloff, 1985).

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Sereno and Lieberman (1987) also found less evidence of coarticulation in children when compared to adults; they conducted a perceptual study in which ten speakers listened to the initial 25 ms of the syllable as spoken by the test subjects. The study included children in the age range of 2 to 7 years and a comparison group of adults. This study examined the effect of the vocalic context on a preceding /k/ phoneme in the syllables /ki/ and /kɑ/. Results indicated that the adults exhibited consistent patterns of anticipatory lingual coarticulation, but for the children however variation in coarticulation was noted. The authors suggest that consistent coarticulatory patterns emerge with the acquisition of the fine-tuned speech motor patterns that accompany maturation.

Some other studies explain that children and adults are having similar patterns of coarticulation. Turnbaugh et.al in 1984, investigated the stop vowel coarticulation in 3 groups of subjects, 3year olds, 5 year olds and adults. Three subjects were taken in each group. Stimuli included stop vowel syllables, stops were /b/, /d/, /g/ and consonants and /i/ and /u/ were the vowels. Results showed that vowels are affected by the anticipatory behavior of consonants. /b/ and /g/ showed large shifts which reflects relative freedom of lingua labial coarticulatory shifts, were as it was reduced in /d/ because alveolar contact reduces markedly the lingual coarticulatory shift induced by vowel context. The F2 onset measured here in stop vowel context are the same for adults, 3 years and 5 years, concluding children having adult like coarticulation. Again study also mentions that the neuromotor antecedents of stop vowel coarticulation may be developed earlier than either temporal control or other kinds of more language specific coarticulation. Sharkey and Folkins in 1985, investigated on the variability of lip and jaw movements as an implication of speech motor control development. 5 adults and 15 children at ages 4, 7, and 10 years produced /mæ/ and /bæ/ 20 times each. The duration of lip-opening movements, jaw-opening movements, lip-open postures, jaw-open postures, and the timing between the onset of lower lip opening and jaw opening was analyzed and there was a decrease in variability between the child and adult groups. No significant differences were observed in the variability of these measures across the child groups. The variability of lower lip displacement decreased significantly between the 4-yedr-old and 7-year-old groups, but not between any other age groups. Jaw displacement variability did not change significantly between any groups. No significant differences in variability were found between /bæ/ and /mæ/. It is hypothesized that different developmental motor processes affect the variability of speech movements at early, intermediate, and older ages. Boyce, 1990 conducted a study on lip rounding in Turkish and English. Study aimed to compare patterns of protrusion movement of upper and lower lip and EMG activity of orbicularis oris for speakers of English and Turkish. Four speakers of American English and four speakers of Standard Turkish produced similarly structured nonsense words designed to show the presence or absence of troughs in lip rounding. Words such as /kuktluk/, /kuktuk/, /kukuk/, /kutuk/, /kuluk/ was taken as stimuli. Results showed Turkish speakers producing "plateau" patterns of movement rather than troughs and unimodal rather than bimodal patterns of EMG activity. Results suggest English and Turkish may have different modes of coarticulatory organization.

Katz et al. (1991) studied both lingual and labial anticipatory coarticulation in a group of 3, 5, and 8year olds and adults. Results indicated that for a /s/ followed by a vowel (/sV/), acoustic measures did not differ as a function of age, which contradicted earlier research by Nittrouer et al. (1989). Authors again found that the magnitude of lingual coarticulation was quite similar for all subjects, both children and adults. This study examined the effect of the vocalic context on a preceding /s/ phoneme in the syllables /si/ and /su/, produced in the carrier phrase *I said* ____. The researchers found no evidence that suggested a greater degree of coarticulation in 3-year-old speakers as compared to older speakers; also the acoustic and video data supported the notion that 3-year-old children coarticulate speech sounds in a manner that is very similar to older children and adults. This conclusion was in support of finding of other researchers (e.g. Sereno et al., 1987; Sharkey & Folkins, 1985; Turnbaugh et al., 1985).

Majority of research in the field of children's coarticulation has commonly involved children 3 years of age or older. However, Goodell and Studdert-Kennedy (1993) designed a study that examined the speech behavior of children as young as 20 months of age. This study also differed from other studies in that it was a longitudinal examination of the maturation of speech production of the child participants across a 10-month time period. The participants of the study were all in the early stages of speech development, ranging in age from 22 to 37 months. The study examined coarticulation of an unstressed schwa in a variety of consonant and vowel contexts. Specifically, the authors investigated the first and second formant frequency patterns of the schwa when embedded in the following nonsense syllables: /bə'bɑ/, /bə'bi/, /bə'dɑ/, /bə'di/, /bə'gɑ/, and /bə'gi/. The researchers found clear differences in duration and coordination of gestures between adults and these relatively young children, as well as a clear shift toward adult-like patterns at about age 3 years. In addition, Goodell and Studdert-Kennedy found that details regarding child-adult differences and developmental changes vary from one aspect of an utterance to another, indicating that intra-subject variation in children may account for much of the discrepancy among previous researchers' findings.

Nittrouer (1993) found that children's tongue gestures are constrained by phonetic context more than those of adults until at least 7 years of age, this study also examined coarticulation by looking at the acoustic characteristics of an unstressed schwa when followed by different consonant-vowel syllables, created by combining the consonants /s/, /ʃ/, /t/, /k/, and /d/ with the vowels /i/, /ɑ/, and /u/. According to the author, the children participating in the study were able to acquire adult-like patterns of jaw movements sooner than they did for tongue movements. In addition, although the children produced gestures similar in shape to those of the adults, many of these speech movements were produced more slowly and with greater temporal variability. In light of these results, the author also concluded that the contradictions in various research findings might arise from differences in test tokens and methods of analysis. Boucher, 2007 investigate anticipatory coarticulation in typically developing young children between the ages of three and six years. This study focuses on the acoustic characteristics of an unstressed vowel, the schwa, and prior to a series of real words. Results indicate that children exhibit adult-like patterns of coarticulation even at a relatively young age. However, the degree of anticipatory coarticulation is dependent upon the phonemic context, with greater differences being evident in a fricative context and less when followed by a stop consonant.

Sussman et al. (1999) conducted a longitudinal study of a child speaker from age 7 months to age 40 months. This study was meant to investigate the earliest developments of coarticulation from babbling through the acquisition of early words, and eventually into segments of running speech. As elicitation of target syllables would prove difficult in infants, the authors extracted (from running speech samples) utterances containing /bV/, /dV/, and /gV/ syllable combinations. The researchers found that for labial sounds in a consonant-vowel context, the participant exhibited a steady increase in coarticulation with chronological maturation. The authors concluded that the child's speech had adult-like patterns of coarticulation by approximately 10 months of age. Results of the study indicate that children develop adult-like patterns of coarticulation for alveolar stops in the prelinguistic babbling stage (7 months of age) and for velar stops by the end of the first year.

Studies have also reported that coarticulation in children varies according to consonant type. Katz and Bharadwaj (2001) state that there are many problems associated with measuring articulatory movement patterns using solely acoustic data. Thus, the researchers chose to examine coarticulatory patterns in kinematic (electromagnetic articulography) and perceptual terms, comparing productions of /sV/ and /ʃV/ in children 4 to 7 years of age. Both kinematic and (preliminary) perceptual data revealed more lingual coarticulation in children for /sV/ than for /ʃV/.

Zharkova, Hewlett, Hardcastle (2008) had done a study on lingual coarticulation. The participants were four adults and four normally developing children aged 6 to 9 years, all speakers of Standard Scottish English. The data were the syllables /_i/, /_u/ and /_a/, in the carrier phrase "It's a … Pam" (ten repetitions). Synchronised ultrasound and acoustic data were recorded using the Queen Margaret University ultrasound system. Extent of consonantal coarticulation and within-speaker variation in child and adult productions were compared according to a new ultrasound-based measure of coarticulation. A significantly greater amount of anticipatory lingual coarticulation was found in children than in adults. Much within-group variability was observed, in both age groups. Within-speaker variability was significantly greater in children than in adults. These results are in agreement with some previous studies. Possible reasons are discussed for some of the contradictions in the literature on child and adult coarticulation.

It is interesting to note that some phonemes impose high coarticulation effect (e.g. /u/) and some do not. Kozhenikov and Chistovich(1965) found that lip rounding for /u/ can start at the beginning of a CCV (consonant – consonant – vowel) syllable, if none of the intervening sounds requires a movement that is antagonistic to it. Ohman (1966) has postulated, from spectrographic evidence that the tongue moves from vowel shape to vowel shape with articulatory gestures for the consonants superimposed on those of the vowels. Daniloff and Moll (1968) found that the lips begin to round for /u/ several phones before the vowel. Bell - Berti and Harris (1979) found orbicularis oris muscle activity for the /u/ at a relatively fixed time before the vowel sound, during the activity for the consonant or consonant cluster preceding it but unaffected by the number of consonants intervening (Raphael, Borden and Harris, 2011)./u/ is a high back vowel which is articulated with the dorsum of the tongue raised toward the roof of the mouth near the juncture between the hard palate and the velum. This is accomplished by contracting the styloglossus muscle which is innervated by hypoglossal (twelfth cranial) nerve. Speakers also round and protrude their lips by contracting the orbicularis oris muscle which is innervated by the facial (seventh cranial) nerve. "The acoustic effect of this positioning of the lips and tongue is threefold: First, the protrusion of lips increases the overall length of the vocal tract and thus lowers the frequencies of all formants. Second, the raising of tongue dorsum pulls the bulk of the tongue out of the pharyngeal cavity, enlarging it and allowing it to resonate to the low – frequency harmonics composing the first formant of this vowel. Third, the posterior constriction formed by the raised tongue dorsum and the protrusion of the lips lengthen the oral cavity, allowing it to resonate to the relatively low – frequency harmonics that make up the second formant of /u/" (Raphael, Borden & Harris, 2011).

Lubker & Gay, 1981, did a study to resolve the differences between two views of anticipatory labial coarticulation. One of these views contends that a speaker begins labial movement toward a rounded vowel in direct relation to the amount of time available while the other view posits an onset of movement that is temporally locked to the rounded vowel. Participants were 4 normal adult American English speakers and 6 normal adults who were native speakers of Swedish. Electromyographic signals were sampled from four muscles associated with labial movement while, simultaneously movements of the upper lip in the anterior-posterior and vertical dimensions were recorded. Material used included both meaningful disyllabic words of each language and non sense disyllabic words. Results suggested that there are a number of purely biological and experimental variables which can intrude upon research of this type, and there are also language-specific differences in the production of rounded vowels which suggest that Swedish and American English speakers have learned different motor-programming goals.

Perumal (1993) investigated the development of production of coarticulation in 4 – 7 year native Kannada speaking children. Six age groups were present with 6 months of interval and 10 children each in each group. Consonants /p/, /t/, /k/ and vowels /a/, /i/, /u/ served as the materials for the study. Results indicated no linear development for coarticulation. It was found that there was an increase in transition duration by the age of 7 years and terminal frequency decreased by the age of 7 years.

The review indicates that coarticulation and its development is language dependent and also variations can be seen in both adults and children. Malayalam as a Dravidian language has extra lip rounding and nasality as its typical feature. The consonant system of Malayalam exhibits a rare five place of articulation contrast in stops and nasals (Mohanan and Mohanan, 1984); whereas English has three places of articulation for stops and nasals. Therefore, the development of coarticulation guided by extra lip rounding, may be different in Malayalam compared to other languages. In this context, the present study investigated the development of anticipatory coarticulation of /u/ in Malayalam speaking children in the age range of 3–6 years. The objectives of the study were (a) to measure transition duration of F_2, (b) terminal frequency of F_2, and (c) extent and speed of transition of F_2 in vowel /u/ when preceded by various consonants in typically developing Malayalam speaking children. The knowledge about the development of coarticulation will enhance our understanding of coarticulatory development and the information obtained from this study can be used for high quality synthesis of children's speech. Further, an understanding of the development of coarticulation in typically developing children will help in diagnosis and rehabilitation of disordered population.

CHAPTER III

METHOD

Participants: Participants were 60 Malayalam speaking typically developing children in the age group of 3 – 6 years with an age interval of 6 months, that is 3< > 3.6, 3.6 < > 4, 4 < > 4.6, 4.6 < >5, 5< > 5.6, and 5.6 < > 6 years. Each group included 10 children.

Following were the inclusion criteria for the participants:

- They shall be native speakers of Malayalam.
- They shall not have any history of hearing and visual impairment, speech and language impairment, cognitive deficits, or any motor deficits at the time of data collection.
- All participants should belong to same socio-economic class.

Material: The material was a list of 14 bisyllabic meaningful words. The structure of the target word was C1V1C2V2, where C1 was /k/ (velar unvoiced stop) /g/ (velar voiced stop), /p/ (bilabial unvoiced stop), /b/ (bilabial voiced stop) /m/ (bilabial nasal), and /j/ (palatal approximant). V1 was either long or short vowel /u/. Pictures depicting the words in a 3 x 3 flash card formed the material. If the child fails in naming the pictures, repetition were given as prompts. Table 1 shows the material of the study.

C1	Word with V1 as /u/	Word with V1 as /u:/
k	kuda kutti kuppi	
g	Guha	
p	Puli puttɘ	pu:vɘ
b	bukkɘ	
m	mudi mutta	mu:ɳa mu:kɘ
j	Juva	

Table 1: Material for the study.

Procedure: Participants were seated comfortably and tested individually. Pictures of the target words were presented visually to the participants who were instructed to name the picture five times. The utterances were audio recorded by placing the microphone at a distance of 10 cm from mouth of the speaker at 44100 Hz sampling frequency using a digital tape recorder (Sony ICD-UX533F audio recorder). The audio recorded samples were given to 3 Speech-Language Pathologist for the correctness utterance of C1V1. Three of the five recordings in which C1V1 are correctly uttered was used for further analysis.

Analysis: The samples were displayed as waveform and bar type wideband spectrograms using PRAAT (Boersma and Weenink, 2012).The following four parameters were extracted for each word.

F_2 Transition Duration (ms): The duration of the formant transition was measured as the time difference in ms between the onset of F2 transition at the beginning of the vowel till the steady state of the same.

Terminal frequency (Hz): Terminal frequency was measured as the frequency of F_2 at the onset of vowel following the stop.

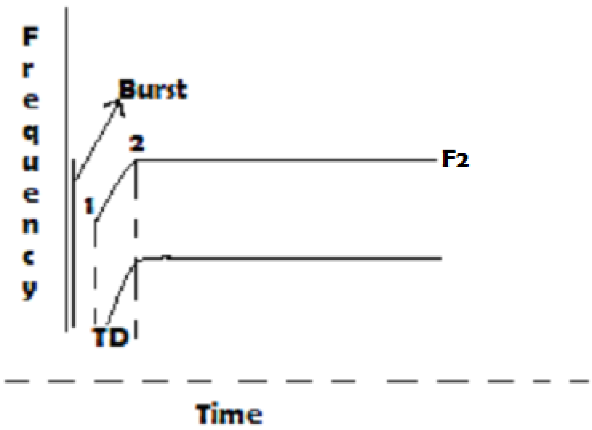
Extent of the F_2 transition (Hz): The extent of the F_2 transition was estimated by calculating the difference in frequency between the terminal frequency of F_2 and the onset of steady state of the vowel.

Speed of F_2 transition (Hz/ms): The speed of F_2 transition is the rate at which F_2 moves and was calculated by the following formula:

$$\text{Speed of } F_2 \text{ transition} = E / D,$$

Where, E is the Extent of F2 transition and D is the Duration of F_2 transition.

Figure 1 illustrates the measurement of the four parameters,



Transition duration of F_2 = 2 – 1

Terminal frequencyof F_2= 1

Frequency of steady state at F_2 = 2

Extent of transition of F_2 = Frequency at 2 ~ frequency at 1

Speed of transition of F_2 = Extent/ transition duration

Figure 1: Illustration of measurement of parameters.

Statistical analysis: Mixed analysis of variance (Mixed ANOVA) was carried out to determine the significant main effect of age (6 age groups) , vowel (short and long vowel) and interaction between age * vowel. Multivariate analysis of variance (MANOVA) was done to determine the significant difference in age group as a function of each CV syllables, and finally repeated measure analysis of variance (ANOVA) was carried out to determine the significant effect of each CV syllables within each group. Multiple comparisons were accounted for by a Bonferroni adjustment.

CHAPTER IV

RESULTS AND DISCUSSION

The results are discusses under the following headings:

1) TERMINAL FREQUENCY OF F2 (F2 TF)

2) F2 TRANSITION DURATION (F2 TD)

3) EXTENT OF F2 TRANSITION

4) SPEED OF F2 TRANSITION

1) TERMINAL FREQUENCY OF F2 (F2 TF)

The mean F2 TF was 1618 Hz and 1223 Hz for short and long vowels, respectively. F2 TF was highest in short vowel /u/ when preceded by palatal (approximant) place of articulation and lowest when preceded by velar place of articulation (stop); in long vowel /u:/, it was highest when preceded by bilabial nasal and lowest when preceded by velar stop. Table 2 shows the mean and SD of F2 TF for all age groups, vowels and place of articulation.

AGE GROUP	/U/				AVG	/U:/			AVG
	STOPS		NASAL	APPROXIMANT		STOPS		NASAL	
	VELAR	BILABIAL	BILABIAL	PALATAL		VELAR	BILABIAL	BILABIAL	
3-3.6	1185 (145)	1277 (188)	1389 (200)	2135 (547)	1497	1025 (131)	1139 (213)	1368 (178)	1244
3.6-4	1285 (216)	1462 (190)	1398 (230)	2286 (484)	1608	1245 (244)	1406 (154)	1550 (353)	1401
4-4.6	1238 (129)	1304 (181)	1472 (291)	2980 (473)	1749	1241 (171)	1243 (247)	1478 (254)	1321
4.6-5	1145 (126)	1244 (131)	1300 (256)	2808 (270)	1624	999 (140)	1208 (232)	1397 (268)	1201
5-5.6	1147 (115)	1179 (90)	1211 (210)	3009 (355)	1637	1065 (87)	1097 (132)	1177 (222)	1113
5.6-6	1064 (119)	1144 (183)	1263 (276)	2894 (328)	1591	1006 (151)	1036 (112)	1315 (330)	1119
AVG	**1177**	**1268**	**1339**	**2685**	**1618**	**1097**	**1188**	**1380**	**1233**

Table 2: Mean and SD of F2 TF (Hz).

Results of MANOVA showed main effect of age [F (5, 53) = 3.263, P< 0.05], vowel [F (7, 371) = 339.454, P< 0.05] and interaction between age*vowel [F (35, 371) = 5.713, P< 0.05]. F2 TF was significantly higher in 4 – 4.6 years of age and significantly lower in 3 – 3.6 years of age. Results of Post hoc Bonferroni indicated significant difference between F2 TF of 4 – 4.6 years of age and other age groups, 3 – 4 years, 4.6 – 6 years. Further, significant difference between short and long vowels was observed. F2 TF of short vowel was significantly higher than that in long vowel. Table 3 shows the F2 TF in all age groups and vowels. Figure 2 shows F2 TF of short and long vowel in all age groups.

AGE GROUP	/U/	/U:/
3-3.6	1497	1244
3.6-4	1608	1401
4-4.6	1749	1321
4.6-5	1624	1201
5-5.6	1637	1113
5.6-6	1591	1119
AVG	**1618**	**1233**

TABLE 3: F2 TF (HZ) IN ALL AGE GROUPS AND VOWELS.

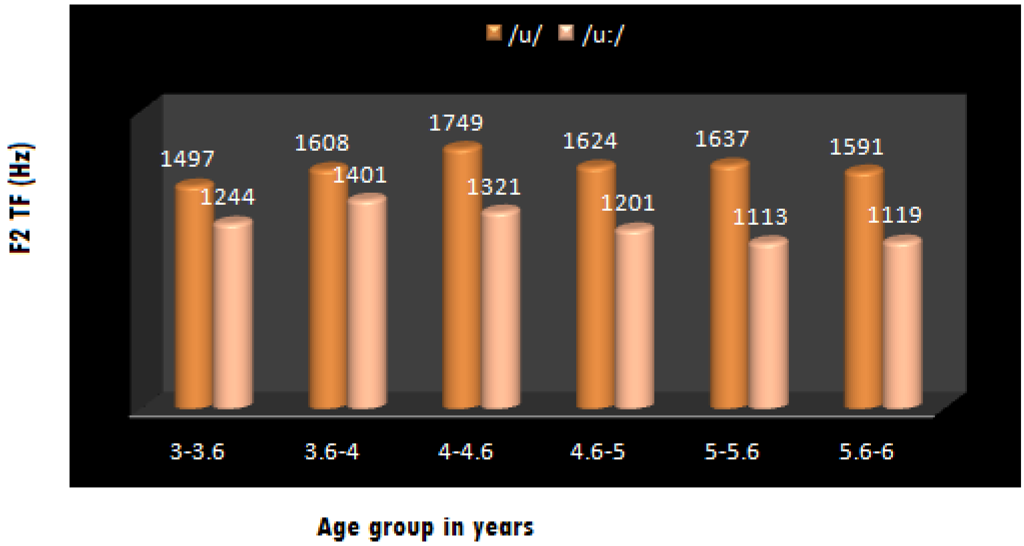


Figure 2: F2 TF of short and long vowel in all age groups.

2) F2 TRANSITION DURATION (F2 TD)

The mean F2 TD was 40.96 and 33.5 for short and long vowels, respectively. F2 TD was longest when preceded by palatal approximant and shortest when preceded by bilabial stop in case of short vowel /u/; in long vowel /u:/, F2 TD was longest when preceded by velar stop and shortest when preceded by bilabial stop. Table 4 shows the mean and SD of F2 TD for all age groups, vowels and place of articulation.

Age group	/u/				Avg	/u:/			Avg
	Stops		Nasal	Approximant		Stops		Nasal	
	Velar	Bilabial	Bilabial	Palatal		Velar	Bilabial	Bilabial	
3-3.6	20 (7)	17 (3)	17 (5)	72 (24)	31.5	31 (23)	23 (6)	23 (3)	25.67
3.6-4	31 (8)	26 (6)	33 (9)	78 (40)	42	40 (11)	35 (11)	40 (11)	38.33
4-4.6	30 (6)	28 (6)	32 (8)	107 (18)	49.25	42 (6)	38 (14)	45 (11)	41.67
4.6-5	32 (7)	27 (5)	32 (7)	(24)	47.5	39 (10)	36 (11)	40 (6)	40.63
5-5.6	19 (4)	17 (3)	19 (3)	82 (23)	34.25	24 (6)	26 (9)	25 (6)	25
5.6-6	24 (7)	20 (6)	27 (17)	94 (21)	41.25	33 (8)	32 (6)	31 (6)	32
Avg	**26**	**22.5**	**26.67**	**88.67**	**40.96**	**34.83**	**31.67**	**34**	**33.5**

Table 4: Mean and SD of F2 TD.

Results of MANOVA showed main effects of age [F (5, 54) = 10.669, P< 0.05], vowel [F (7, 378) = 247.011, P< 0.05] and interaction between age*vowel [F (35, 378) = 1.557, P< 0.05]. F2 TD was significantly higher in 4 – 4.6 years of age and significantly shorter in 3 – 3.6 years of age. Results of Post hoc Bonferroni indicated significant difference between 3 – 3.6, 5 – 5.6 years of age and other age groups, 3.6 – 5 years. Further, significant difference between short and long vowels was observed. F2 TD of short vowel was significantly longer than that in long vowel. Table 5 shows the F2 TD in all age groups and vowels. Figure 3 shows F2 TD of both vowels in all age groups.

Age Group/	/u/	/u:/
3-3.6	31.5	25.67
3.6-4	42	38.33
4-4.6	49.25	41.67
4.6-5	47.5	40.63
5-5.6	34.25	25
5.6-6	41.25	32
Avg	**40.96**	**33.5**

Table 5: F2 TD (ms) in all age groups and vowels.

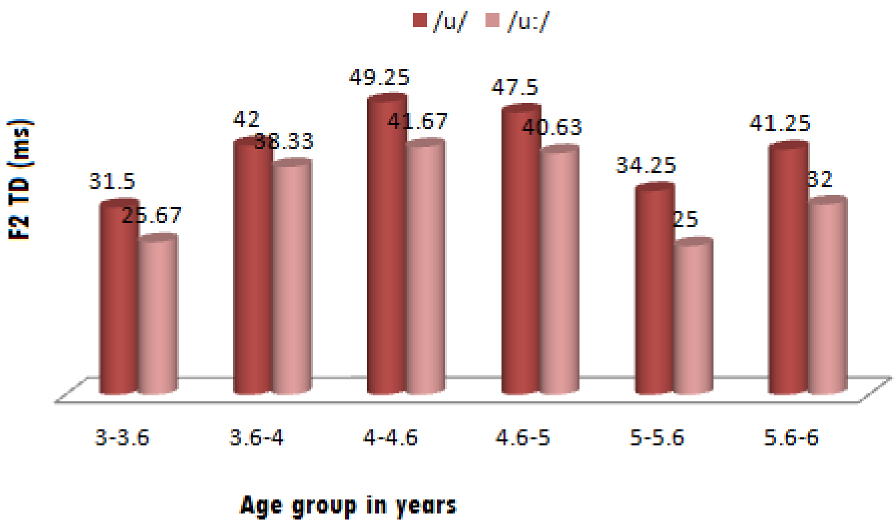


Figure 3: F2 TD (ms) of both vowels in all age groups.

3) EXTENT OF F2 TRANSITION

The results indicated that mean extent of F2 transition was 439 ms and 205 ms for short and long vowel, respectively. Extent of F2 transition was highest when preceded by palatal approximant and lowest when preceded by velar stop for short vowel /u/ and more when preceded by bilabial nasal and less when preceded by velar stop. Table 6 shows the mean and SD of extent of F2 transition for all age groups, vowels and place of articulation.

Age group	/u/				Avg	/u:/			Avg
	Stops		Nasal	Approximant		Stops		Nasal	
	Velar	Bilabial	Bilabial	Palatal		Velar	Bilabial	Bilabial	
3-3.6	188 (49)	177 (54)	183 (64)	682 (269)	**307.5**	142 (34)	168 (54)	175 (31)	**161.7**
3.6-4	252 (60)	247 (70)	224 (70)	689 (352)	**353**	248 (70)	300 (88)	260 (66)	**269.3**
4-4.6	214 (85)	217 (58)	219 (63)	1252 (397)	**475.5**	210 (61)	229 (82)	257 (45)	**232**
4.6-5	200 (43)	195 (40)	219 (65)	1439 (321)	**513.3**	191 (20)	205 (38)	242 (34)	**212.7**
5-5.6	141 (30)	195 (52)	203 (69)	1439 (421)	494.5	147 (39)	183 ((49)	192 (51)	**174**
5.6-6	165 (44)	201 (52)	195 (63)	1394 (290)	**488.8**	165 (61)	186 (45)	186 (35)	**179**
Avg	**193.3**	**205.3**	**207.2**	**1149.2**	**438.8**	**183.8**	**211.8**	**218.7**	**204.8**

Table 6: Mean (Hz) and SD of extent of F2 transition.

Results of MANOVA showed main effects of age [F (5, 54) = 9.217, P< 0.05], vowel [F (7, 378) = 361.513, P< 0.05] and interaction between age*vowel [F (35, 378) = 9.188, P< 0.05]. Extent of F2 transition was significantly longer in 4.6 – 5 years of age and significantly shorter in 3 – 3.6 years of age for short vowel /u/; it was significantly longer in 5.6-4 years of age and significantly shorter in 3-3.6 years of age in long vowel /u:/. Results of Post hoc Bonferroni indicated significant difference between 3 – 3.6 years of age and other age groups, 4 – 6 years of age and other age groups. Further, significant difference between short and long vowels was observed. Extent of F2 transition short vowel was significantly longer than that in long vowel. Table 7 shows the extent of F2 transition was in all age groups and vowels. Figure 4 shows extent of F2 transition was in all age groups and vowels.

AGE GROUP	/u/	/u:/
3-3.6	307.5	161.7
3.6-4	353	269.3
4-4.6	475.5	232
4.6-5	513.3	212.7
5-5.6	494.5	174
5.6-6	488.8	179
AVG	**438.8**	**204.8**

Table 7: Extent of F2 transition was in all age groups and vowels.

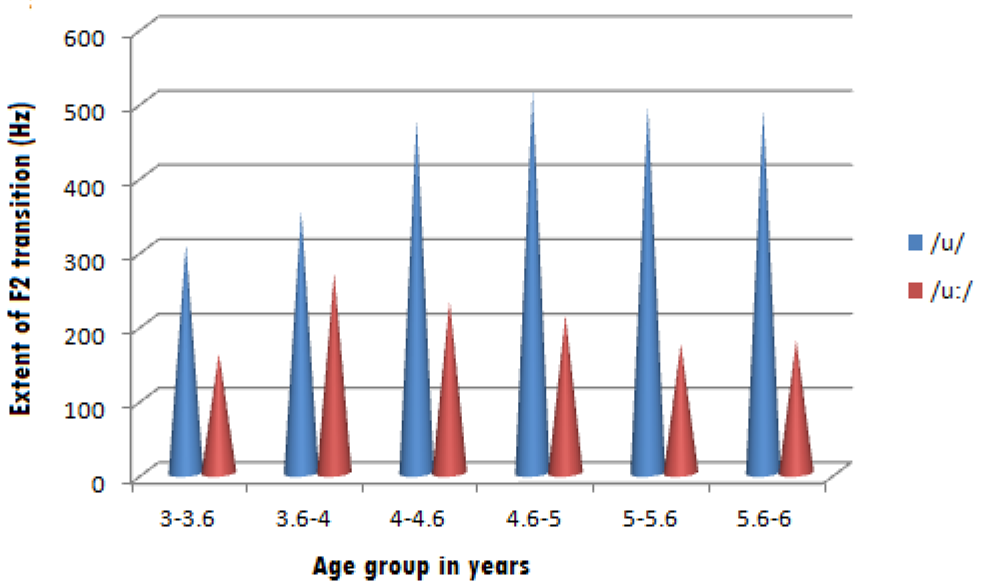


Figure 4: Extent of F2 transition was in all age groups and vowels.

4) SPEED OF F2 TRANSITION

The results indicated that mean speed of F2 transition was 9.5 ms and 6.7 ms for short and long vowel, respectively. Speed of F2 transition was highest when preceded by palatal approximant and lowest when preceded by velar stop in short vowel /u/; it was highest when preceded by bilabial nasal and lowest when preceded by velar stop in long vowel /u:/. Table 8 shows the mean and SD of speed of F2 transition for all age groups, vowels and place of articulation.

AGE GROUP	/u/				AVG	/u:/			AVG
	STOPS		NASAL	APPROXIMANT		STOPS		NASAL	
	VELAR	BILABIAL	BILABIAL	PALATAL		VELAR	BILABIAL	BILABIAL	
3-3.6	8 (2)	11 (4)	9 (2)	9 (2)	**9.25**	7 (2)	7 (4)	9 (5)	**7.7**
3.6-4	8 (2)	10 (2)	8 (3)	9 (3)	**8.75**	7 (2)	10 (4)	7 (2)	**8**
4-4.6	7 (2)	9 (2)	6 (2)	12 (2)	**8.5**	5 (1)	8 (4)	6 (1)	**6.3**
4.6-5	6 (1)	8 (1)	7 (1)	13 (4)	**8.5**	5 (1)	6 (2)	6 (1)	**5.7**
5-5.6	9 (2)	11 (4)	10 (3)	16 (2)	**11.5**	6 (1)	7 (2)	8 (2)	**7**
5.6-6	6 (2)	11 (4)	9 (3)	15 (3)	**10.25**	5 (2)	6 (2)	6 (2)	**5.7**
AVG	**7.3**	**10**	**8.2**	**12.3**	**9.5**	**5.8**	**7.3**	**7**	**6.7**

Table 8: Mean (Hz/ms) and SD of speed of F2 transition.

Results of MANOVA showed main effects of age [F (5, 54) = 5.247, P< 0.05], vowel [F (7, 378) = 15.834, P< 0.05] and interaction between age*vowel [F (35, 378) = 2.181, P< 0.05]. Speed of F2 transition was significantly less in 4.6 – 5 years of age and significantly high in 5.6 - 6 years of age in short vowel /u/ and significantly low in 4.6 – 5 years of age and significantly high in 3.6 - 4 years of age in long vowel /u:/. Results of Post hoc Bonferroni indicated significant difference between 5 – 5.6 years and other age groups; 3 – 5 and 5.6 – 6 years. Further, significant difference between short and long vowels was observed. Speed of F2 transition of short vowel was significantly high than that in long vowel. Table 9 shows the speed of F2 transition in all age groups and vowels. Figure 5 shows the speed of F2 transition in all age groups and vowels.

AGE GROUP	/u/	/u:/
3-3.6	9.25	7.7
3.6-4	8.75	8
4-4.6	8.5	6.3
4.6-5	8.5	5.7
5-5.6	11.5	7
5.6-6	10.25	5.7
AVG	**9.5**	**6.7**

Table 9: Speed of F2 transition (Hz/ms) in all age groups and vowels.

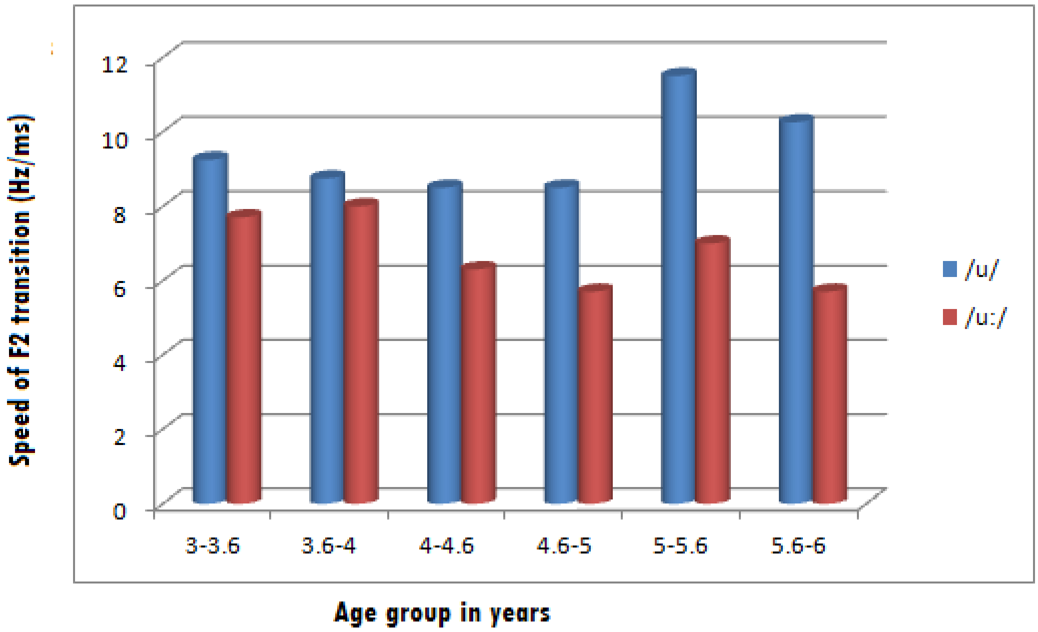


Figure 5: Speed of F2 transition (Hz/ms) in all age groups and vowels.

To summarize, the mean terminal frequency of F2 was longer in short vowels compared to long vowels. Mean terminal frequency of F2 was highest when preceded by palatal approximant and lowest when preceded by velar stop in short vowel /u/; it was highest when preceded by bilabial nasal and lowest when preceded by velar stop in long vowel /u:/. F2 TF was significantly higher in 4 – 4.6 years of age and significantly lower in 3 – 3.6 years of age. There was significant main effect of age and vowel. F2 TF of short vowel was significantly higher than that in long vowel.

The mean transition duration of F2 was significantly longer in short vowel compared to long vowel. Transition duration of F2 was longest when preceded by palatal approximant and shortest when preceded by bilabial stop in case of short vowel /u/; in long vowel /u:/, F2 TD was longest when preceded by velar stop and shortest when preceded by bilabial stop. There was significant main effect of age and vowel. F2 TD was significantly higher in 4 – 4.6 years of age and significantly shorter in 3 – 3.6 years of age. F2 TD of short vowel was significantly higher than that in long vowel.

The mean extent of F2 transition was significantly higher in short vowel compared to long vowel. Extent of F2 transition was higher when preceded by palatal approximant and lower when preceded by velar stop for short vowel /u/ and higher when preceded by bilabial nasal and lowest when preceded by velar stop. There was significant main effect of age and vowel. Extent of F2 transition was significantly higher in 4.6 – 5 years of age and significantly lower in 3 – 3.6 years of age for short vowel /u/; it was significantly higher in 5.6-4 years of age and significantly lower in 3-3.6 years of age in long vowel /u:/. Extent of F2 transition in short vowel was significantly higher than that in long vowel.

The mean speed of F2 transition was significantly higher in short compared to long vowel. Speed of F2 transition was highest when preceded by palatal approximant and lowest when preceded by velar stop in short vowel /u/; it was highest when preceded by bilabial nasal and lowest when preceded by velar stop in long vowel /u:/. There was significant main effect of age and vowel. Speed of F2 transition was significantly lower in 4.6 – 5 years of age and significantly higher in 5.6 - 6 years of age in short vowel /u/ and significantly lower in 4.6 – 5 years of age and significantly higher in 3.6 - 4 years of age in long vowel /u:/. Speed of F2 transition of short vowel was significantly higher than that in long vowel.

CHAPTER V

DISCUSSION

The results indicated several points of interest. First of all, ***the mean terminal frequency of F2 was longer in short vowels compared to long vowels.*** Even if one considers that this may be because of the effect of palatal approximant, it is not so. Excluding palatal approximant, the mean terminal frequency of F2 in short vowel was 1261 and that in long vowel was 1233. The result could be attributed to the length of the vowel. In short vowel there is a need for the articulator to traverse faster from on articulatory position to another. Hence it may be possible that the terminal frequency of F2 is higher in short vowel compared to long vowel.

Second, ***the mean terminal frequency of F2 was highest when preceded by palatal approximant and lowest when preceded by velar stop in short vowel /u/.*** This is expected as palatals are known to have higher F2 compared to other places of articulation. Hence the terminal frequency should also be higher in vowel preceding a palatal. The lowest terminal frequency in vowel when preceded by velar stop was interesting. It was also interesting to note that ***the mean terminal frequency of F2*** was highest when preceded by bilabial nasal and lowest when preceded by velar stop in long vowel /u:/. Savithri (1989) reported F_2 of 1216 Hz in /k/, 1162 Hz in /g/, 1095 Hz in /p/, 1103 Hz in /b/ and 900 Hz in /m/ in Kannada. As per the data if these phonemes are followed by /u/ the terminal frequency should have been lowest for bilabial. While the findings call for more research, it could be presumed that a constriction at the lip end has strong influence on the preceding and following phonemes. The vowels investigated in the present study (/u/ and /u:/) have constriction at the lip end. Bilabials also have constriction at the lip end and hence may not be influenced so much by these vowels. Velars may be strongly influenced by these vowels in that the articulatory positioning may be fronted.

Third ***the terminal frequency of F2 was significantly higher in 3.6-4 years of age and significantly lower in 5 –5.6 years of age (combined data excluding palatal approximant).*** The results may be attributed to the vocal tract volumes of these children. The results are not in consonance with the results of Repp (1986) which revealed that a 4-year-old speaker did not display systematic differences in their schwa production across the different linguistic contexts, whereas a 9-year-old and adult speaker did exhibit such differences. The results of the present study are in consonance with that of Perumal (1993) who reported no linear development for coarticulation. Sereno and Lieberman (1987) suggest that consistent coarticulatory patterns emerge with the acquisition of the fine-tuned speech motor patterns that accompany maturation. ***The terminal frequency of F2 was significantly higher in 3.6-4 years of age even after e***xcluding palatal approximant as shown in figure 6. The data suggested no developmental trend on the terminal frequency of F2.

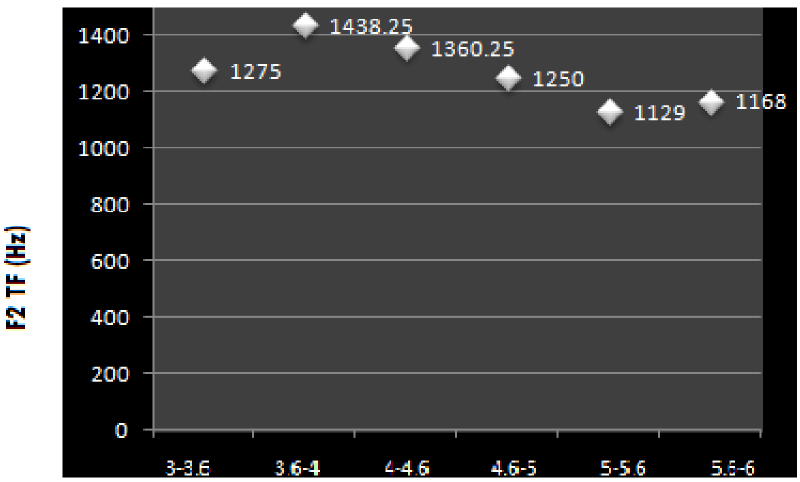


Figure 6: F2 TF in various age groups (Combined data of short and long vowel excluding palatal approximant).

Fourth, ***the mean transition duration of F2 was significantly longer in short vowel compared to long vowel.*** The results can be partly attributed to inclusion of palatal approximant. The mean transition duration of F2 was 25 ms and 34 ms in short and long vowels, respectively when palatal approximant was excluded. Savithri (1989) reported transition duration of around 33.5 ms. The result could be attributed to the length of the vowel. In short vowel there is a need for the articulator to traverse faster from on articulatory position to another and hence a shorter transition duration.

Fifth, ***transition duration of F2 was longest when preceded by palatal approximant and shortest when preceded by bilabial stop in case of short vowel /u/; in long vowel /u:/, F2 TD was longest when preceded by velar stop and shortest when preceded by bilabial stop.*** Approximants are usually longer as it comprises of two vowels (/i/ and /a/ in this case). It is possible that the final vowel (/a/) of the approximant is modified to /u/ because of coarticulation, thus leading to a longer TD. Bilabial stops and nasals have lip constriction similar to vowels /u/ and /u:/ and hence may take less time to transit from consonant to vowel.

Sixth, ***F2 TD was significantly higher in 4 – 4.6 years of age and significantly shorter in 3 – 3.6 years of age***. The results are not in consonance with that of Perumal (1993). Perumal (1993) reported an increase in transition duration by the age of 7 years and terminal frequency decreased by the age of 7 years. No developmental trend was noticed. A linear trend was observed as in figure 7.

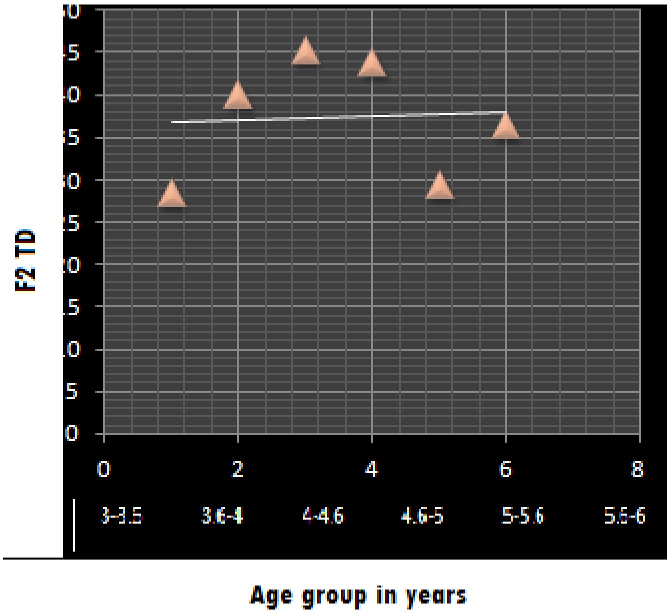


Figure 7: F2 TD in various age groups with a linear line superimposed.

Seventh the ***mean extent of F2 transition was significantly higher in short vowel compared to long vowel.*** This is expected as the articulator is quickly moving from one articulator to another and the terminal frequency is higher in short vowel. Extent of F2 transition was highest when preceded by palatal approximant and lowest when preceded by velar stop for short vowel /u/ and highest when preceded by bilabial nasal and lowest when preceded by velar stop. The result that extent of F2 transition was highest when preceded by palatal approximant is expected as palatals have the highest F2. Savithri (1989) reported F_2 of 1216 Hz in /k/, 1162 Hz in /g/, 1095 Hz in /p/, 1103 Hz in /b/ and 900 Hz in /m/, 1944 Hz in /c/, and 1927 Hz in /j/ in Kannada. Going by the presumption that velars might be strongly influenced by these vowels in that the articulatory positioning may be fronted, it is expected that the vowels will have lowest extent of F2 when preceded by velars.

Eighth, ***extent of F2 transition was significantly higher in 4.6 – 5 years of age and significantly lower in 3 – 3.6 years of age for short vowel /u/; it was significantly longer in 5.6-4 years of age and significantly shorter in 3-3.6 years of age in long vowel /u:/.*** This relatively higher extent of F2 transition in 4.6 – 5 year old children may reflect articulatory adjustments in lip rounding and motor planning. The format trajectories in various age groups would look as in figure 8.

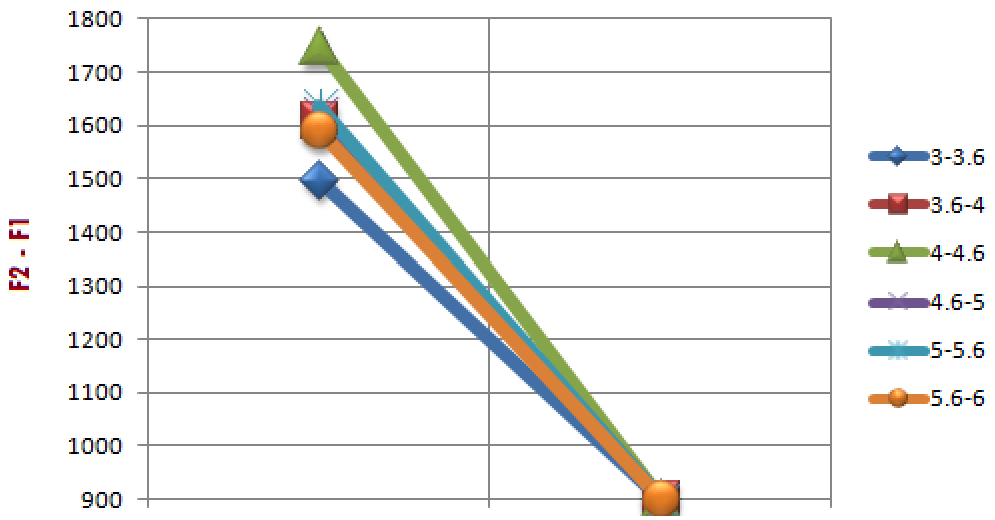


Figure 8: Formant trajectories in various age groups (frequency of second formant of vowel is fixed at 900 Hz).

Ninth, ***the mean speed of F2 transition was significantly greater in short vowel compared to long vowel***. Speed was calculated as extent/ duration. Extent was higher in short vowel and duration shorter (excluding palatals) and hence speed would be greater. Speed of F2 transition was longest when preceded by palatal approximant and shortest when preceded by velar stop in short vowel /u/; it was longest when preceded by bilabial nasal and shortest when preceded by velar stop in long vowel /u:/. This could attribute to higher extent and shorter F2 transition duration. Speed of F2 transition was significantly lower in 4.6 – 5 years of age and significantly higher in 5.6 - 6 years of age in short vowel /u/ and significantly shorter in 4.6 – 5 years of age and significantly longer in 3.6 - 4 years of age in long vowel /u:/. This also could attribute to higher extent and shorter F2 transition duration.

The results are important and interesting in that the rounded vowels extend an anticipatory coarticulation more so on the palatal approximant. No developmental trend was noticed, although 4.6-5 years old children show a different trend compared to children in other age groups. The results have contributed to the literature on coarticulation. Future studies on (a) other Indian languages comparing results in Malayalam, (b) comparing the data with adults are warranted. Also, the reason that children in the age group of 4.6-5 year are different needs to be investigated.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The present study investigated the development of anticipatory coarticulation of /u/ in Malayalam speaking children in the age range of 3–6 years. The objectives of the study were (a) to measure transition duration of F_2, (b) terminal frequency of F_2, and (c) extent and speed of transition of F_2 in vowel /u/ when preceded by various consonants in typically developing Malayalam speaking children. The knowledge about the development of coarticulation will enhance our understanding of coarticulatory development and the information obtained from this study can be used for high quality synthesis of children's speech. Further, an understanding of the development of coarticulation in typically developing children will help in diagnosis and rehabilitation of disordered population.

Participants were 60 Malayalam speaking typically developing children in the age group of 3 – 6 years with an age interval of 6 months, that is 3< > 3.6, 3.6 < > 4, 4 < > 4.6, 4.6 < >5, 5< > 5.6, and 5.6 < > 6 years. Each group included 10 children.

The material was a list of 14 bisyllabic meaningful words. The structure of the target word was C1V1C2V2, where C1 was /k/ (velar unvoiced stop) /g/ (velar voiced stop), /p/ (bilabial unvoiced stop), /b/ (bilabial voiced stop) /m/ (bilabial nasal), and /j/ (palatal approximant). V1 was either long or short vowel /u/. Pictures depicting the words in a 3 x 3 flash card formed the material. If the child fails in naming the pictures, repetition were given as prompts. Table 1 shows the material of the study. Participants were instructed to name the picture 5 times. The samples were displayed as waveform and bar type wideband spectrograms using PRAAT (Boersma and

Weenink, 2012) and the terminal frequency of F2, duration of transition of F2, extent and speed of transition of F2 were measured.

The results indicated several points of interest. First of all, ***the mean terminal frequency of F2 was longer in short vowels compared to long vowels.*** Even if one considers that this may be because of the effect of palatal approximant, it is not so. Excluding palatal approximant, the mean terminal frequency of F2 in short vowel was 1261 and that in long vowel was 1233. The result could be attributed to the length of the vowel. In short vowel there is a need for the articulator to traverse faster from on articulatory position to another. Hence it may be possible that the terminal frequency of F2 is higher in short vowel compared to long vowel.

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