SPEECH PERCEPTION IN CHILDREN: TEMPORAL ASPECTS

FUNDED BY

DEPARTMENT OF SCIENCE & TECHNOLOGY

MINISTRY OF SCIENCE & TECHNOLOGY

GOVERNMENT OF INDIA

NEW DELHI

No.Sp/SO/N02/92

DEPARTMENT OF SPEECH SCIENCES

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ACKNOWLEDGMENTS

The Investigator acknowledges the Department of Science & Technology for funding the Project. She is thankful to Dr S Nikam, Director, AIISH, Mysore for providing her with all the facilities to run the Project. Dr N P Nataraja, Professor & Head, Department of Speech Sciences, AIISH, Mysore is acknowledged for the help & encouragement given in completing this project.

Dr T V Ananthapadmanabha, Executive, Voice & Speech Systems, Bangalore has provided the softwares necessary for the project & the staff, Department of Electronics, AIISH, Mysore have prepared the visual forced-choice response paradigm which have been extremely useful in the project. The research staff appointed on the project, though shifted to permanent jobs, have been very hard working & have done their best to see that the experiments in the project were completed. They have also taken pains to see that the scientific articles are written & have reached the organizing secretaries, conferences at the appropriate time. The Investigator expresses her gratitude to all of them & wishes that such a team would be available for future research. She especially thanks Sri P Rajeev & Ms Swapna who have helped in compiling the final Report.

The children who have participated in the experiments of this project have to be heartily thanked for their enthusiastic & patient participation for the Speech Production & Speech Perception tasks.

The investigator Thanks Ms Lalitha, Computer Operator, Ms Susheela Bai, Stenographer, & Ms N Sridevi, Research Assistant all at the Department of Speech Sciences, AIISH Mysore for their helpful gesture.

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LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PUBLICATIONS

1. Closure duration in production and perception
   JASI, 22 (3), 1994, 189-194.

2. Development of voicing contrast in speech production - VOT, JAIISH, 1995, In press.

3. Development of voicing contrast in speech perception - VOT JAIISH, 1995, In press.

4. Emergence of voicing contrast in children
   JAIISH, 1995, In press.

5. VOT: A comparison in speech production and speech Perception - proceedings of the First Technical Session Madras-India Regional Chapter of the Acoustical Society of America, 1995, 10.

6. VOT in Speech production, JAIISH, 1995, In press.

7. VOT in Speech Perception, JAIISH, 1995, In press.

8. Transition duration in Speech Production and Speech Perception, will be presented at National Symposium on Acoustics, Hyderabad, 1996.

CHAPTER I

INTRODUCTI ON

" Anyone who has tried to work in this area will attest to the ingenuity, skill & patience required in conducting rigorous experiments with immature reporters (children).."

Yeni Komshian (1980)

One of the continuing questions posing those interested in verbal language acquisition is whether the child's perception of the speech signal is the same as, or different from, adult perception of the same signal. Whether the child first distinguishes only the coarser contrasts between the sounds which reaches his ear is a continuing question.

The processing of speech signals within the existing constraints of natural language has interested and excited scientists for many years. The ear seems to be custom built for the purpose of detecting and analyzing sounds. The speech signals which are long spurts of a complex and constantly changing stream of sounds radiate from the speaker's lips, travel in air, impinge upon the ear drum of the listener and reach the higher cortical structures through middle and inner ears and the auditory pathways. The speech signal is analyzed at lower centres (below the thalamus level) to some extent and processing of specific speech parameters and other complex acoustic features of natural stimuli begins only at the levels of medial geniculate body

(MGB) which is located in the thalamus (Kiedel, Kallert, Korth and Humes, 1983). The linguistic components are added only at the higher centres of the cortex to the already analyzed signal to reconstruct the percept intended by the speaker. When the listener has reconstructed this signal (i.e. decoded and interpreted) speech perception is said to have occurred.

It is known that the acoustic features in speech change during the first six years & this is also considered to be fairly systematic (Kent, 1976). Evidence for this also comes from the results of the studies by Preston & Yeni-Komshian (1967), Preston, Yeni-Komshian & Stark (1967), Preston & Port (1968,1969), Eguchi & Hirsh (1969), Port & Preston (1972) & Zlatin (1974). This has probed researchers in the area of speech perception to investigate whether normal children perceive speech as they produce. Further, in recent years, speech & language clinicians increasingly have been confronted with children who exhibit language disorders in the absence of any underlying factor such as hearing loss, mental retardation etc. Some investigators (Hirsh,1959; Bakker,1967; Doehring,1968; RosenthaI,1972; TaI I a I & Stark,1980) have suggested that these children are impaired in their perception of the speech signal, while others maintain that the signal is perceived adequately, but that a deficit lies at a more conceptual or cognitive level.

There have been many experiments in the past 20 years that have aimed to test speech perception in children (AsIin & Pisoni,1980, Barton,1980, Strange & Broen,1980, Best et a1,1991). Efforts have been made by all these researchers to explore speech perception in children. Three alternative conceptions have been proposed on the relation between perception & Production:

1. The child's perception of the phonological system is complete by the time the child begins to acquire productive control of phoneme contrasts (Compton, 1975; Smith, 1973). The child is assumed to perceive all the phoneme contrasts of the target language in the same way that adults do. According to this model, there are major discrepancies between perception & production: many contrasts that are perceived are not produced. These discrepancies have been characterized by a set of "rewrite rules". For example the child may perceive the contrast between the initial phonemes of the words wing & ring but produce /win/ in both instances. The rewrite rule describing this discrepancy can be written as:

$$\left\{ \begin{array}{c} /w/ \\ /r/ \end{array} \right\} \longrightarrow [w] \;/\; \#\_\_\_\_$$

2. Other theorists hypothesize that both the child's perception & production of the phonological system differ from the adult model. At any point In time the child's

system is internally consistent; the child produces all & the only contrast that he or she perceives. The child's system is described either as completely related to the adult system (Kornfeld, 1974) or as a reduction or simplification of the adult system (Garnlca, 1971). Within this model, the child who produces /win/ for the lexical items ring & wing & does not perceive the difference between the initial phonemes of these words. In his or her system, they are homophones.

3. A third theoretical alternative claims that both perception & production develop gradually over the first several years. However, the perception of a contrast generally precedes the production of that contrast- (Edwards, 1974; Menyuk & Anderson, 1969; Zlatin & Koenigsknecht, 1976). At first, a given contrast is neither perceived nor produced; later, the contrast is perceived but not produced, & still later, the contrast is both perceived & produced.

The evidences from the results of research in this area is puzzling. On the one hand, perception of at least some acoustic-phonetic dimensions appears to be determined by biologically given predispositions that are operable shortly after birth. On other hand, perception by adults of these same acoustic-phonetic dimensions reflects to a high degree their specific linguistic experience. In general, they perceive phoneme contrasts only if they produce them in their language. Clearly, a great deal of modification of perceptual abilities take9 place between infancy and adulthood as the individual learns his or her language (Strange & Broen, ig80).

"It is important in our understanding of this modification process to document the 9tatus of phoneme perception during the years the child is acquiring the phonology in production. However, it is here that our empirical base is most wanting. Until recently, much of the evidence regarding perception was inferential in nature, based on the behavior of one or two subjects and with little systematic control. Some direct perceptual studies have examined only small numbers of children and have utilized informal testing procedures in which the exact nature of the stimuli was not specified. Others (Zlatin & KoenIgsknecht, 1975) examined only children who have acquired the contrast that is being tested" (Strange & Broen 1980).

While this area has received some attention at the international level, the scene at the national level is dismal. Although these sources of data are useful, there is a pressing need for direct experimental evidence on the development of phonological perception. Both cross-sectional and longitudinal studies are needed with groups of children of sufficient size to allow at least preliminary generalizations about normative development. It is of equal importance that these studies utilize stimulus materials that allow for the precise specification of the acoustic-phonetic dimensions that children do and do not differentiate at various stages of development. In this context, the present study was undertaken. The objectives of the study are as follows:-

1> To investigate the development of speech production (Temporal Parameters) in Kannada speaking normal children in the age group of 4-7 years.

2> To investigate the development of speech perception (Temporal parameters) in Kannada speaking normal children in the age range of 4-7 years.

3> To compare the results obtained on speech production & speech perception & to suggest diagnostic methods for those who have abnormal perception.

It is hoped that the research in this area in normal children will delineate new insights into the mechanisms involved in the neurological basis of Speech and Language processing. Knowledge about speech perceptual process will facilitate in the understanding of the Auditory perceptual processing in children with perceptual deficits, communicatively handicapped and phono logically disordered. In addition, the results of the Experiment may lead to better understanding of the etiology of specific developmental language disabilities that could ignite improved diagnostic and therapeutic techniques in speech and language handicapped. The results will definitely help in bridging the gap between infant and adult perceptual mechanism and formulation of the theory which can also account for the developmental years and transitions in perceptual responses.

Also, developmental research directed specifically to co-vary multiple acoustic parameters will be enlightening with respect to the possible changes in the relative/combined strength of acoustic parameters as perceptual cues for voicing in Kannada. Further, the controversial issue whether/not the speech perception deficits exist in individuals who have no known organic disorders but who exhibit deviant production skills could probably get an answer.

The outcome of this study has clinical implications. The study derives significance from the point of clinical application. Talkers with normal articulations may move their articulators with precision and perceive the differences brought so by the articulators. Such articulatory and perceptual organization is missing in the hear ing-impaired, phonologically disordered and those with perceptual deficits. It becomes imperative to include the speech production and perception data into the schedules of training the handicapped. As there is a developmental trend, one must exercise caution while considering the age group for which such training may be adopted. This should add to a positive trend in the rehabilitation of those with perceptual deficits.

It is hoped that an audio-cassette will be prepared based on the results, which could be used for the evaluation and rehabilitation of those with perceptual deficits (hearing-impaired & learning disabled). Clearly it is impossible to cover all questions of all sorts. However, a sufficient sampling of future challenges has been taken here to be solved to a certain degree. This may stimulate the desire to dig deeper, to know more, to experiment and implement. It is hoped that this research will be of much interest to advance the understanding of nature of mechanism and representations that mediate speech perception during ch iIdhood.

In addition this line of research may help us to determine which aspects of acoustic and phonetic analysis are critical for normal language development. Finally, it is hoped that speech perceptual research will lead to a better understanding of some type of developmental language disabilities that in turn, may lead to improved diagnosis and treatment for these children.

CHAPTER II

STOP CONSONANTS: THEIR NATURE

Stop consonants are produced by occluding the oral cavity & releasing the articulator after sufficient air pressure is built up. Acoustically stop consonants have five distinct segments : viz:

a) A period of occlusion

b) A transient explosion

c) A brief period of frication

d) A period of aspiration &

e) Transition to the following vowel

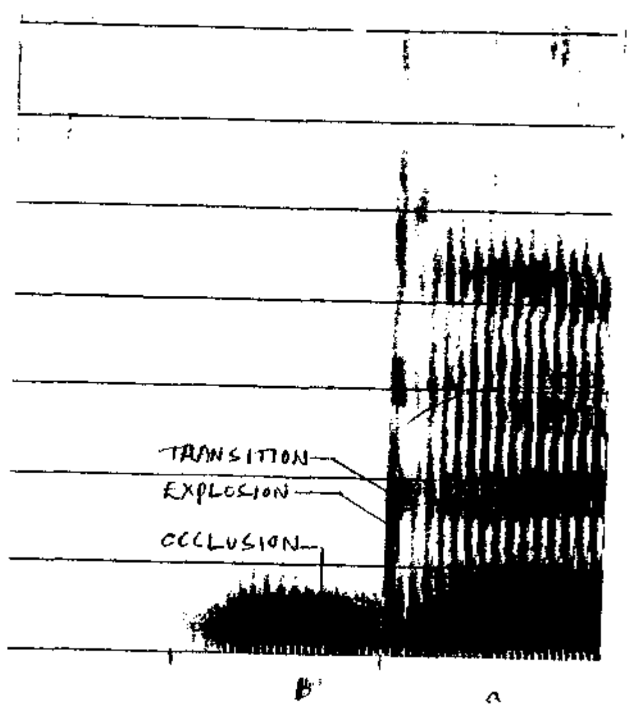

Figure 2.1: Spectrogram depicting /ba/

Stop consonants are considered to be special because of several reasons. First of all they are unsteady sounds & require a very high level of processing in the auditory system. Studdert-Kennedy & Liberman propose a special decoder for stop consonants. Second, they have so many perceptual cues & the importance of cues is not yet understood. Third, the cues of stops trade for frequency & temporal parameters.

In Kannada, there are sixteen stop consonants as In Table 2.1.

Voiceless		Voiced		Place
Unaspirated	Aspirated	Unaspirated	Murmured	of articu1ation
k	kh	g	gh	Velar
t	th	d	dh	Retroflex
t	th	d	dh	Dental
P	ph	b	bh	Bilabial

Table 2.1: Stop consonants in Kannada

In Kannada, the velars & retroflexs are characterized by mid frequency bursts, the dentals by high frequency bursts & the bilabials by low frequency bursts. The voiceless are longer than the voiced & the preceding vowel is longer for the voiced than for the voiceless.

Several Important differences exist between the stops of Kannada & English, which Is as listed below.

1> While in English, stops have a two way classification, in Kannada, they have a four way classification. Also, in English, the distinction between Voiceless aspirated & Voiceless unaspirated is phonetic, & in Kannada it is phonemic.

2> In English, stops appear in the final position of the word while in Kannada, it does not.

3> In English, by rule, the stop consonants in the initial position are aspirated, while in Kannada It is not.

4> In English, there exist three places of articulation for stops, while in Kannada there are four places of articulation.

CHAPTER-III

VOICING CUE TO INITIAL STOPS

EXPERIMENT-I : DEVELOPMENT OF VOICING CONTRAST : VOT AS A CUE FOR INITIAL STOPS

Measurements of VOT have been widely used for differentiating between voiced and unaspirated voiceless stops. It should be noted, however, that VOT is only one aspect of a complex array of distincts including onset pitch, Closure Duration, spectral shape during closure burst, amplitude in others.

VOT is defined as the difference in time between the release of a complete articulatory constriction and the onset of quasiperiodic vocal fold vibration and is considered a major cue for differentiation of prevocalic stops along the voicing dimension (Lisker and Abramsom, 1964, Abramson and Lisker, 1965).

When languages have a "traditional" voiced vs voiceless stop contrast in initial position (Eg. Arabic, Bulgarian, Efik, Japanese) with no aspiration involved, then VOT has been used in particular to differentiate the two. The differences in VOT have been termed lead vs short lag for voiced and voiceless respectively (Lisker and Abramson, 1964, Yeni Komshian et al. 1967, Keating, et al. 1981). Across languages Lisker and Abramson (1964, 1967) indicated that there appears to be a fairy consistent 60 msec minimum difference in VOT between voiced and voiceless stops.

Keating (1984) posits that these differences may be quantal & anchored to the region of the burst.

In the procedures for specification of VOT the instant of the burst release is denoted as zero. Negative values expressed in msec, indicates the time by which VOT leads the release and positive values indicate the lag time (Lisker and Abramson, 1967 a). Fig. 3.1 depicts the lead, short lag and long lag VOT.

VOT IN SPEECH PRODUCTION:

The acquisition of voicing or VOT contrast for stop consonants is of interest as <1> a wide variety of languages employ VOT to distinguish homorganic stop consonants (Lisker & Abramson, 1964), <2> languages partition the VOT continuum yielding varied voicing contrasts among homorganic stops (Abramson & Lisker, 1965: Williams, 1977), <3> infants are able to perceive some characteristics of voicing in stop consonants from soon after birth (Eimas, Sequiland, Jusczyk & Vigorito, 1971; Eilers, Morse, Gavin & Oiler, 1981) & <4> linguistic experience has been shown to effect the discrimination of certain categories of voicing in stop consonants (Eilers, Gavin & Wilson, 1979).

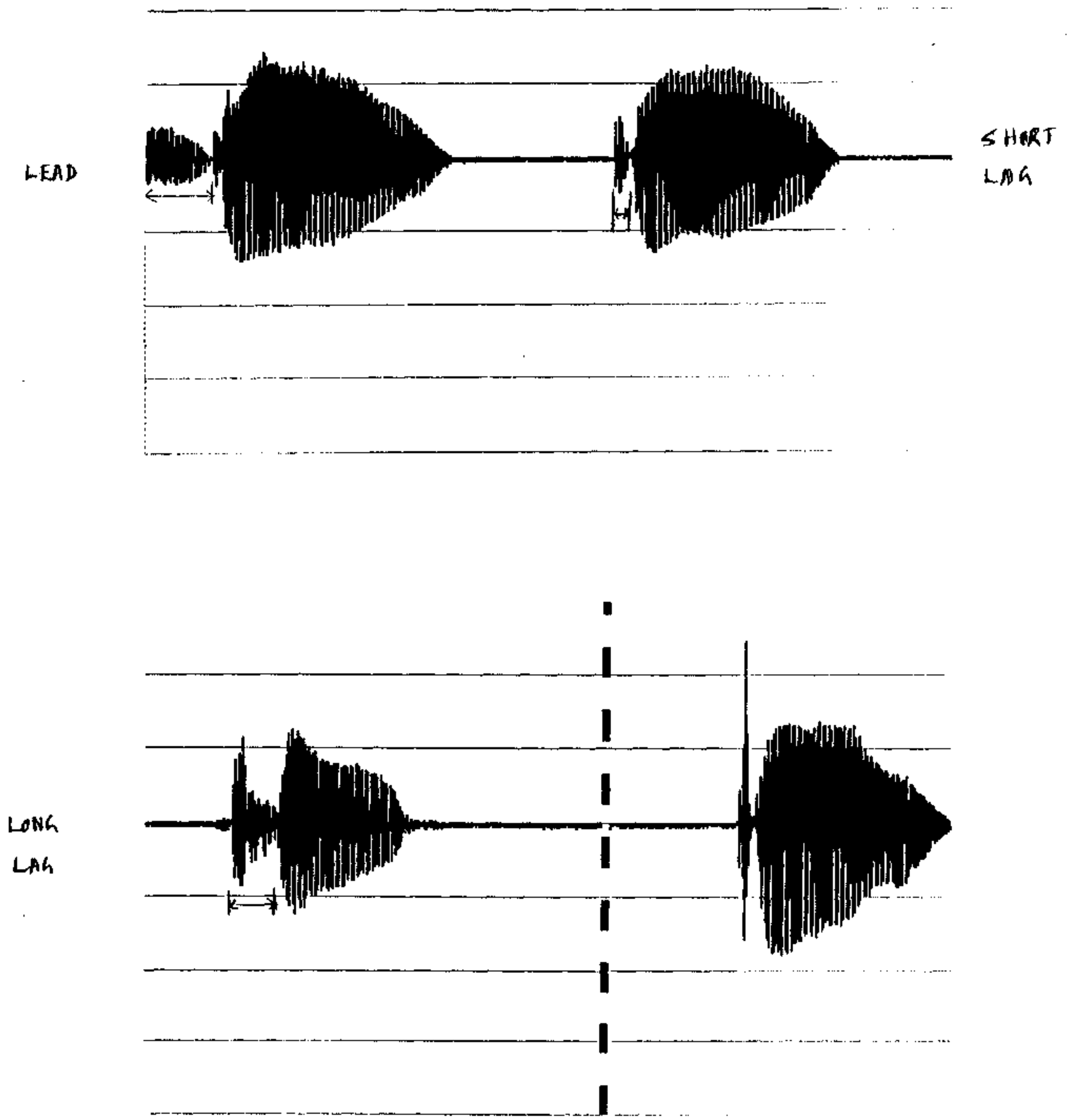

Figure 3.1: Waveforms depicting lead, short lag & long lag VOT.

The research on speech development in children has given due importance to VOT as an important temporal feature. VOT has been found to be longer during early childhood (Preston Yeni Komeshian & Stark (1967).Kewely Port & Preston (1974), Winterkorn, MacNeilage & Preston (1976). It has been stated that the changes in the VOT distribution that occur during the first 6 years of life appear to be fairly systematic. Eguchi & Hirsh (1969), Kent (1976) have opined that the distinctive acoustic cue VOT is helpful to asses the general process of motor skill acquisition, since VOT production distributions appropriate to the children's language are acquired during the period of speech sound learning.

VOT values will change concomitantIy as the child acquires productive control over voicing (Morley 1965). According to Macken & Barton (1974), the acquisition of voicing contrast takes place in three stages viz., (1) with no contrast (2) with short lag and (3) voiced and voiceless contrast. VOT for voiceless cognates is shorter for children compared to adults and while children use short lag range for the production of voiced stops, adults use short lead range. At the age of 6 years, there is a clear cut distinction between voiced and voiceless cognates with short and long lag respectively (Zlatin & Koenegskenecht 1976).

VOT IN SPEECH PERCEPTION:

As in speech production studies, the data from the studies with synthetic speech have suggested that the acoustic characteristics providing the simplest and most direct indication of whether a stop consonant is voiced or unvoiced is VOT. While the studies on adults reveal VOT as a cue for voicing contrast, those on children indicate a developmental trend.

Two early attempts to study categorical perception in children were seen as offering support for the notion that development is not involved in speech sound categorization. Winterkorn, MacNeilage and Preston (1967) tested five 3 year olds on six stimuli from a /da-ta/ VOT. They attempted to train the children to perform two different motor responses, one for each of the extreme stimulus items (-30 and +100 msec. VOT). After several sessions this experimental plan was abandoned-largely because the task was not easily assimilated by the children and the reinforcement contingencies, however varied, was not over to produce orderly participation in the task". Subsequently, the children worked with an experimenter who played a game in which she said da-da-da dime or ta-ta-ta time and thereby induced them to imitate target syllables. Last, the test tape was played in what might be called a test of identification generalization for the four intermediate stimuli. Winterkorn et al (1967) reported that the children's responses were adult like.

However, it may be observed that, If stimuli are placed at sufficiently wide intervals, even a continuous response may appear categorical. That is, the stimulus interval will encompass completely the category boundary. In this case the items on either side of the category boundary differed by 25 msec VOT. This is a sufficiently large interval to encompass a fairly gradual category boundary. A similar test for adults might employ 5 msec intervals and the crossover might occur within 5-10 msec. The children's perception may well have differed from adults but the test was not sensitive enough to demonstrate a difference.

Yeni Komshian, Preston and Cullen (1967) studied the perception of VOT difference between voiced and voiceless apical stops based on children's ability to imitate, synthetic CV syllables. The authors presented a greater number of stimuli, and found that the majority of their 5-6 year old children did not demonstrate the ability to distinguish between apical cognates in the manner consistent with the above study. In effect, only 4/12 subjects evidenced phoneme boundary width between /g/ categories at about +35 msec. on the same stimuli, other children gave a singular response to all VOT vibrations [For eg. /d/] or produced sounds which were not always consistent with stop consonants /t/ and /d/ [for Eg. /h] closure.

Wolf (1973) found no difference between kindergarten and II grade children when they identified and discriminated stimuli from /da-ta/ and /ba-pa/ VOT continua. She interprets her results as support for the idea that categorical perception is innate and states that her results are comparable to those obtained with adults. However, adults were not tested and data from 5 and 7 year olds were not appropriately applied to questions of nativism, since the children had already been exposed to massive amounts of linguistic stimulation by that time. In view of results from other studies discussed below, the failure to find developmental differences is not surprising. Statistically significant age comparisons typically involve a wider age range and/or include younger children.

Zlatin and Koenigsknecht (1975) reported significant differences between age groups in a study of voicing contrasts cued by VOT. Subjects were adults and children aged 2 and 6 years. Stimuli for labial /b-p/ and apical/d-t/ continua were at 5 msec, steps from 0 msec VOT to +60 msec VOT and the continuum also included stimuli at +70 and +80 msec VOT. There were two bilabial continua. Velar tokens between +25 and +60 msec VOT were at 5 msec steps, then 10 msec, steps, to 135 msec. The 10 judgments for each of the 15 stimuli on each of four continua is a demanding procedure for young children.

The results were subjected to analysis of the 50% crossover points, the 75% crossover points for each category (Voiced and Voiceless) and the distance between 75% points or boundary width. The boundary width measure was found to be most sensitive to age differences. The adults category boundaries were steepest, with 97.5% of boundary widths ranging between 3 and 15 msec. Of the ten 6 year olds, three had velar boundary widths in excess of 15 msec, and one exceeded 15 msec, on the labial series. In general, the 2 year olds boundaries were significantly wider than 6 year olds on two continua. Eight of the ten 2 year old's boundaries exceeded 15 msec on the labial series. One did on the apical series and five did on the velar series. Of course, the narrower the boundary, the more categorical the response. It is important to note that Zlatin and Koenigsknecht data included occurrences of multiple 50% crossovers i.e. curves were not unimodal in 7 cases among the 2 year olds, 3 among 6 year olds and two among adults.

Multiple 50% crossover represent significant departures from categorical perception. The subject is responding at a chance level at more than one position on the stimulus continuum. The authors however, averaged across multiple crossovers within a subjects data to obtain a single 50% crossover value. This may be probably unwise since this response type is qualitatively and quantitatively different from categorical perception.

Zlatin and Koenigsknecht speculate on the reason for their results and state that "The observation that boundary width decreases with age suggests that there is a systematic reduction in the amount of difference required for making the distinction between prevocalic cognates on the basis of variations in VOT. They report with little comment the finding that crossover points for velar were placed at significantly longer VOTs by the 2 year olds. (The other continua did not produce similar results).

Simon (1974) suggested a developmental/maturational difference in VOT phoneme boundaries. He found that young children used a simpler speech perceptual system with fewer and coarser acoustic features than the adult's system. He supports a relation between perception and production of speech between subjects 6-14 years of age. He also found that significant larger DL for 4-6 year old was less sharp than 14 years old. He expected that the younger children should have less sharper boundaries. Since these children have only recently acquired some confidence in manipulating the adult phonological system and are still not sure of themselves in extreme situations of forced choice.

Studies have also been found in literature which report shifts in crossover positions as a function of age. Simon and Fourcin (1978) tested French and British children between the ages of 2 and 14 years using stimuli that varied in VOT and First Formant characteristics. This study is exceptional in that stimuli were generated semifactorially rather than as a one dimensional continuum. That is, for VOTs *less* than 30 msec, F1 was either level/rising. The rationale for this variable was that, in English, the extent of the F1 transition is greater for voiced than for voiceless stop consonants (Liberman, Delattre and Cooper, 1958) and level F1 influences subjects to prefer a voiceless response (Summerfield and Haggard, 1977). Using a factorial design allows the investigator to observe the effects of variables that may contribute unequally to the perception of some speech sound contrast.

In this study, each child contributed only three responses for each stimulus item and data are presented in grouped format. The authors provide a characterization of overall response types across age. The pattern which emerged for British children was the following -

(1) Children of 2 and 3 years were most consistent in their responses to stimuli from end points of the continuum. These children labeled intermediate items in a random fashion.

(2) Children's responses to individual stimulus items became more consistent as age increased, and by 4 years, responses were categorically divided between the two response possibilities.

(3) Children 2 and 3 years did not respond differentially to the absence of a rise in F1 in stimuli with short VOT. However, in the data from 4.5 and 6 year olds, there is evidence the children were more reluctant to label as voiced stimuli with steady F1. Data for 8, 11, 12, 13,

14 year olds exhibit a strong migration of data points for steady state F1 stimuli toward the unvoiced response alternative.

French children did not respond at all to the F1 variable which may not be important in their learning (Simon and Fourcin, 1978). They also lagged somewhat behind their English counterparts in achieving categoricalness in labeling. Simon and Fourcin suspect that the sharpness of category boundary increases "with the number of co-operating distinctive acoustic features".

A study by Strange and Broen (1980) used an extensive set of pretest identification trials in examining identification of approximate consonants. 21 children between 2:11 and 3:5 and adults were tested. They looked at the distribution of individuals crossovers for each of their three continua. Children differed from adults in the modal positions for boundaries on /r/ - /I/ and /w/ - /b/ continua. In addition, there was more variability among children than adults in boundary locations.

Series of studies conducted by Tallal and Stark (1980), Elliot et al. (198.6,87), and Sussman and Carney (1989) have added a new dimension to developmental research in terms of experimental paradigm and measurement of perception of Just Noticeable Differences, and Fine grained Auditory discrimination.

Elliot et al. (1986) demonstrated age related differences in VOT discrimination using a same/different simple adaptive procedure (Witt, 1971) with trial by trial visual feedback/reinforcement and "Catch" trials. The experimental paradigm used in that study measured Just Noticeable Differences (JNDs) or the smallest VOT differences that could be discriminated 50% of the time relative to the end points of the VOT continuum. The adaptive procedure focuses test trials on those stimuli for which responses provide the greatest amount of information for each particular subject. This **renders adaptive** procedure **particularly attractive for testing children, since the test** session may then be as short as possible.

Elliot (1986) further developed the study (the above study had discrimination when an adaptive procedure was used and trials were concentrated among pairs of stimuli that were discriminated 50% of the time), the major purpose of which was to determine whether the same types of age effects would be replicated for new groups of subjects and a different task in which all stimuli were presented equal number of times. An eight item, 5 formant consonant vowed (CV) continuum in which VOT ranged from 0-35 msec. was used. The same different task presented all possible pairs of CV syllables in which VOT differed by 10 and 20 ms and an equal number of catch trials that contained identical CVs. Results showed that children displayed poorer discrimination than adults for CV pairs differing by both time intervals. Adults displayed a somewhat greater tendency to respond "same" than the children. The outcomes support the results of the previous study and were interpreted as representing the true age related differences in VOT discrimination.

Sussman and Carney (1989) found that children aged 5 through 10 performed differently from adults in a selective adaptation task. Although, adults demonstrated changes in phonetic category labeling **after** exposure to repeated presentation of one stimulus (the adapter) children did not. Sussman and Carney (1989) speculated that children as old as 10 might be lacking in the auditory abilities necessary for a selective adaptation effect.

Boundary shift phenomenon has been observed with bilinguals (Caramazza, Yeni-Komshian, Zurif and Carbone, 1973; Williams, 1980). Data reported in separate studied by Williams for Monolingual English Adults (1979 a) and children (1979 b) showed that /b/ - /p/ boundaries change systematically with age [19 ms for 8 to 10 year olds, 21 ma for 14 to 16 year olds, and 25 ms for adults]. Post hoc tests also revealed that the adult boundaries occurred at significantly longer VOT values than the 8 to 10 year olds. Williams (1980) reports that, as a function of Increased length of exposure to English, native Spanish speakers (ages 8 to 10 years and 14 to 16 years) moved their /b/ - /p/ Voicing boundary increasingly toward the English boundary. Caramazza et al (1973) found that unillngual French Canadians seemed "relatively insensitive to VOT as a categorical phonological cue" but that bilinguals whose second language was English were more sensitive to VOT although still not as sensitive as unilingual English speakers. These results from bilinguals show that the boundaries between categories are subject to experimental effect even during adolescence (Williams, 1980).

Flege and Eefting (1986) examined production and perception of the contrast between /t/ - /d/ by subjects differing in native language and age. Acoustic analysis revealed that native speakers of English realized word initial /t/ with significantly longer VOT values (approximately 85 ms) than native speakers of Spanish (approximately 19 ms). Native English and Spanish adults realized /t/ with VOT values that were non-significantly longer than those of 9 year olds of the same native language background. Native English adults realized prevoiced /d/ more often than English children but Spanish adults and children realized /d/ with lead VOT values in nearly every instance. In a labeling task, the native English speakers showed steeper identification functions and category boundaries at significantly longer VOT values, than age matched native Spanish subjects. The boundaries of both the native English and Spanish adults occurred at significantly longer VOT values than those of children who spoke the same language. Three possible explanations were offered for the effect of age on stop voicing judgments, the auditory processing of acoustic parameters associated with stop changes with age, listeners require an increasingly long VOT interval to perceive /t/ as they get older because they produce /t/ with somewhat longer VOT values, listeners use their perception to optimally match the stops they hear.

Eilers (1983) showed that Spanish learners appeared to use specific linguistic experience at an early age to master perceptually less salient lead vs short lag contrasts.
Burham, Earnshaw and Clarke (1991) investigated the effect of specific linguistic experiences on categorical perception which would be reflected by different developmental courses for the perception of native and non-native contrast. English language environment infants, 2 to 6 years old children and adults were tested for their identification of sounds on a native voiced/voiceless, bilabial stops from -70 ms to +70 ms VOT in 10 ms steps and non-native prevoiced/voiced bilabial stop speech continuum. Categorical perception of the two contrast diverged as a function of age increasing for the native contrast and decreasing for the non-native between 2 and 6 years.

The results of the cross-Ianguage studies indicate the significant role language plays in the perception of voicing. Depending on the nature of stop consonants available in a particular language, the voicing contrast differs.

Several investigators (Tallal and Piercy, 1974; Thibodeau and Sussman, 1979; Tallal, Stark, Kullman and Mellits, 1980; Elliott, Busse, Patridge, Rupert and Degraff, 1986; Elliot and Busse, 1987; Elliott and Hammer, 1988) have reported the perceptual abilities in children with communication disorders. However, the exact nature of the relationship between auditory speech perception and production disorders remains obscure.

The review indicates (1) a developmental trend (2) cross language differences and (3) perceptual deficits in communication disorders. Developmental research to examine emerging patterns and differentiation of VOT cue to voicing is important. Though the review throws light on this aspect, the subjects selected in most of the studies are in various age groups (discontinuous) and are in non-Indian languages. There is a need for longitudinal studies involving a large number of subjects in order to identify the development of production and perception of VOT in normal children. In this context, the present experiment was planned.

The aim of this experiment was to investigate the development of VOT in Speech production & perception (in initial position) in 4-1• year old Kannada speaking normal children and adults (18-28 years).

METHODOLOGY

PART A : SPEECH PRODUCTION

MATERIAL: Three voiceless unaspirated stop /k/ (velar), /t/ (dental) and /p/ (bilabial) and their voiced cognates (g, d, b respectively) in the initial position of six meaningful Kannada words (kadi, gadi, tada, dada, padi, badi) formed the material.

SUBJECTS: Six Kannada speaking normal children each in the age range of 4-5, 5-6 and 6-7 years [3 boys and 3 girls in each group] and six adults (3 males & 3 females) were selected for the present study. All the subjects (tad normal speech and hearing.

METHOD: The subjects were instructed to repeat the word after the experimenter into a microphone (AKJ) which was kept at a distance of 10cms from the mouth. The list of six words was randomised and iterated five times. The repetitions of all the 30 tokens of each subject were audio-recorded on to a cro2 audio-cassette.

These audio recordings were subjected to acoustic analysis to extract the VOT of the stop consonants. The output of the tape recorder was connected to the auxillary input of the DSP Sonograph Model 5500 (Kay Elemetrics) and the waveform along with the spectrogram was displayed on the dual channel of the DSP Sonograph at 8 K Hz and 2 sees time interval. VOT was measured by referring to the waveform and the spectrogram. VOT was measured as the duration between the release of a complete articulatory constriction or burst transient and the onset of phonation for the following vowel in case of voiceless stops (lag VOT) and till the onset of phonation for voiced stops (lead VOT). A note was made whenever a lag VOT was present for voiced stops and cessation of voicing, if any; was also noted.

ANALYSIS: The data was tabulated and the mean VOT of the five trials for each word was calculated. Also the range of VOT and the "S-Ratio' were computed (S-Ratio = Mean VOT of voiced plosives Mean VOT of voiceless plosive).

PART B: SPEECH PERCEPTION

TASK I: GENERATION OF SYNTHETIC STIMULI

MATERIAL : Three stop consonants in the initial position ie. voiced velar /g/, voiced dental /d/ and voiced bilabial /b/ were selected for this experiment. Three meaningful bisyllabic Kannada words with these stop consonants In the initial position were considered. These words formed a minimal pair with a change from voiced plosive to voiceless plosive. Table - 3.1 shows the words selected for the Experiment-I.

Phoneme	Bisyllabic words	
	Voiced	Voiceless
/g/	gadi	kadi
/b/	badi	kadi
/d/	dada	tada

Table 3.1: Words selected for the experiment

An adult native Kannada speaking normal female aged 23 years served as the speaker (subject). The three words with voiced stop in the initial position were written, one each on a card and the subject was visually presented with one card at a time and was instructed to alter the word in a natural manner into a microphone (cardiode unidirectional), kept at a distance of 10 cms from the mouth in a sound treated room of the Speech Science Laboratory. These were recorded on a data acquisition system and were then digitized on a computer PC-AT-386 DX with a sampling rate of 16,000 Hz and 12 bit resolution and stored in the computer memory. The digitized waveform was displayed on the screen of the computer using the program DISPLAY on the SSL developed by VSS (Voice and Speech System, Bangalore). The original VOT was measured using both the waveform display and spectrogram of SSL (VSS) for each of the stop consonants.

The synthetic tokens of VOT were generated using the waveform Editor of SSL-VSS software (voice and Speech Systems, Bangalore). The original lead VOT was truncated in terms of three pitch periods from a continuum between lead VOT to 0 msec. When VOT was "o' synthetic tokens with lag VOT were generated by inserting silence in steps of 1O msec between the burst and the following vowel (The "o" VOT contained only the burst). The details of the original and the synthetic stimuli are in Table 3.2.

VOT Stimulus	I /g/	/b/	/d/
Original SO	-96	-70	-88.8
S1	-82	-50	-76.4
S2	-68	-38.4	-59.8
S3	-57	-22.4	-44.0
S4	-41	0	-28.0
S5	-27	10	0
S6	0	20	10
S7	10	30	20
S8	20	**40**	30
S9	30	50	40
S1O	40	-	50
S11	50	—	—
Total no. of tokens	120	100	110

Table 3.2: Synthetic stimuli for VOT

Each word with its synthetic tokens was considered as a test and within each of the three tests, the tokens were randomized and iterated ten times. These synthetic tokens with truncated VOT in three places of articulation were then audio-recorded on a metallic cassette with an inter-token-interval (ITI) of 3 sees and inter stimulus interval (ISI) of 5 sees. Ten practice items preceding the experimental stimuli were also recorded. This served as test material for VOT which consisted of a total of 330 synthetic tokens.

An example of original VOT and truncated VOT are presented for all three places of articulation in the fig. 3.2.

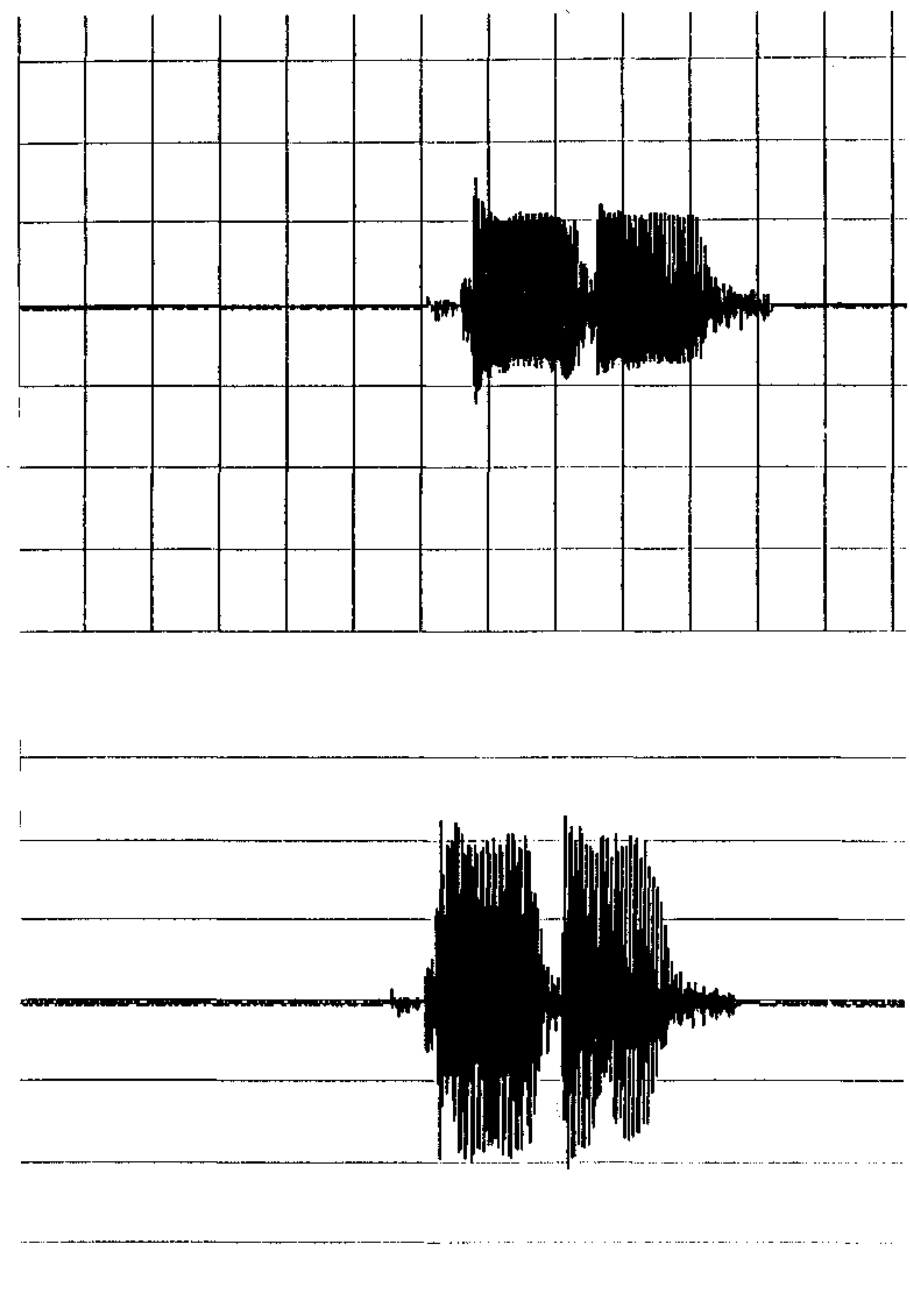

Figure 3.2: Waveform depicting original & truncated VOT.

TASK 2: PERCEPTUAL EVALUATION

STIMULI : The synthetic tokens of VOT audio-recorded on the metallic cassette formed the stimuli for perceptual evaluation.

SUBJECTS: Six native Kannada speaking normal children each in the age range of 4-5, 5-6 and 6-7 years and six Kannada speaking normal adults in the age range of 18-28 years participated in the perceptual evaluation. All subjects had normal speech and hearing on screening.

The subjects were required to identify accurately the VOICED-UNVOICED cognate in the initial position of the minimal pairs with 100% accuracy during an initial practice trial. Subjects falling to show 100% correct identification for these original exemplars during the trial period were eliminated from the main test. This requirement served as a check on the attentiveness of the children.

METHOD: Children were tested individually. The subject was seated facing the response keyboard (indigenously prepared) ([Photo-1] which consisted of two cartoons which would glow when the button was pressed. The child was conditioned to press the left button for one of the word [word consisting of voiced stop] and the right button for another word [word consisting of unvoiced stop]; when the child pressed the

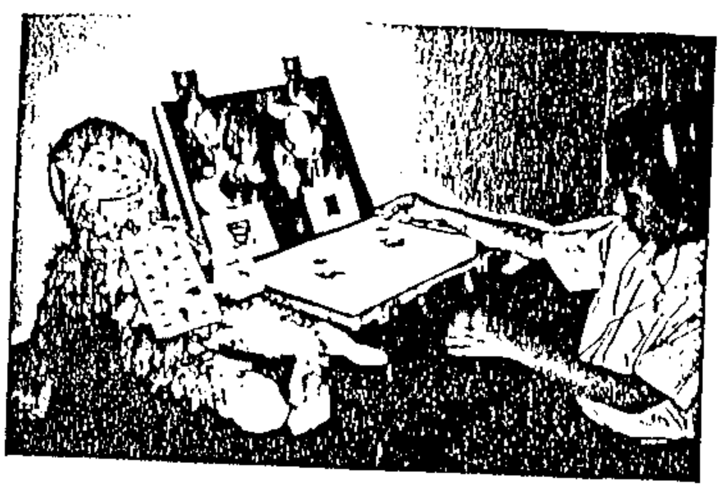

Photo 1: Response Key Board.

button the cartoon would glow which reinforced the child. Also a play mode was adopted to make the task enjoyable for the child. The tape recorder was covered with a life sized doll of popular cartoon figure and children were instructed that the cartoon would speak to them.

Each subject was shown two pictures to be used in the perceptual test. Practice was provided using live voice to familiarize the children with the labeling procedure. This procedure consisted of having the child point to the picture illustrating the stimulus which was perceived and say the label associated with the picture.

If there was a discrepancy between what the child seemed to be saying and the picture to which he/she was pointing, clarification was sought by the experimenter. After the child correctly responded to 10 practice items with live voice, the 10 taped practice items were presented.

If the child correctly responded 100% of the time, the response keyboard was introduced and the actual testing commenced. Stimuli were presented through earphones (Philips circumaural) at comfortable **listening levels**. The experimenter recorded the chiId's response on a alternate forced choice sheet immediately **after the child's** response.

Testing was done *over* few days with breaks between sessions. A total of 330 responses for each child and a total of 59400 responses for children were collected.

For adults, the stimuli was presented through headphones & they were instructed to write their response on a alternate forced choice response sheet. A total of 1980 responses were obtained for adults.

ANALYSIS: The data obtained was tabulated and the percent response for each stimuli for the child was calculated by the following formula:

$$\frac{\text{Obtained number of response for the stimuli}}{\text{Total number of iterations}} \times 100$$

The percent response for voiced and voiceless Stop consonant was tabulated for each of the test stimuli on the basis of which the identification and discrimination function for each test stimuli was plotted. Four measurements were obtained from the identification function [modified from Lisker and Abramson, (1967) which was originally given for VOT by Doughty (1949)J which were as follows:

1. 50% crossover: It is that point on the graph which was the actual or interpolated point about the acoustic cue continuum for which 50% of the subjects response corresponds to the voiced (voiceless) category. For example in the fig. 3.3 50% crossover will be 55 msec, of CD, that is the point ~B' on the X-axis.

2. Lower Limit of Phoneme Boundary Width : It wns defined an that point along the acoustic cue continuum where an individual identified voiced (voiceless) stop 75% of the

time. For eg. in the above fig. LL will be 37 msec, of CD ie the point A on the X-axis.

3. Upper Limit of Phoneme boundary Width: It was defined as the corresponding point for the identification of the (voiced) voiceless cognate 75% of the time. For example in the figure the UL will be 73 msec. of CD ie the point 'C' on X-axis.

4. Phoneme Boundary Width (msec): Between voicing category was defined as the arc boundary cross point along the acoustic cue continuum and was determined by subtracting the lower limit from upper limit, for example in the figure the PBW is 36 msec.ie.. 73-37 [C-A] (Fig 3.3).

Means and standard deviations were calculated for each of the measurements for each age group and across place of articulation. Mann- Whitney test was used to bring out the significant difference between age, sex and place of articulation.

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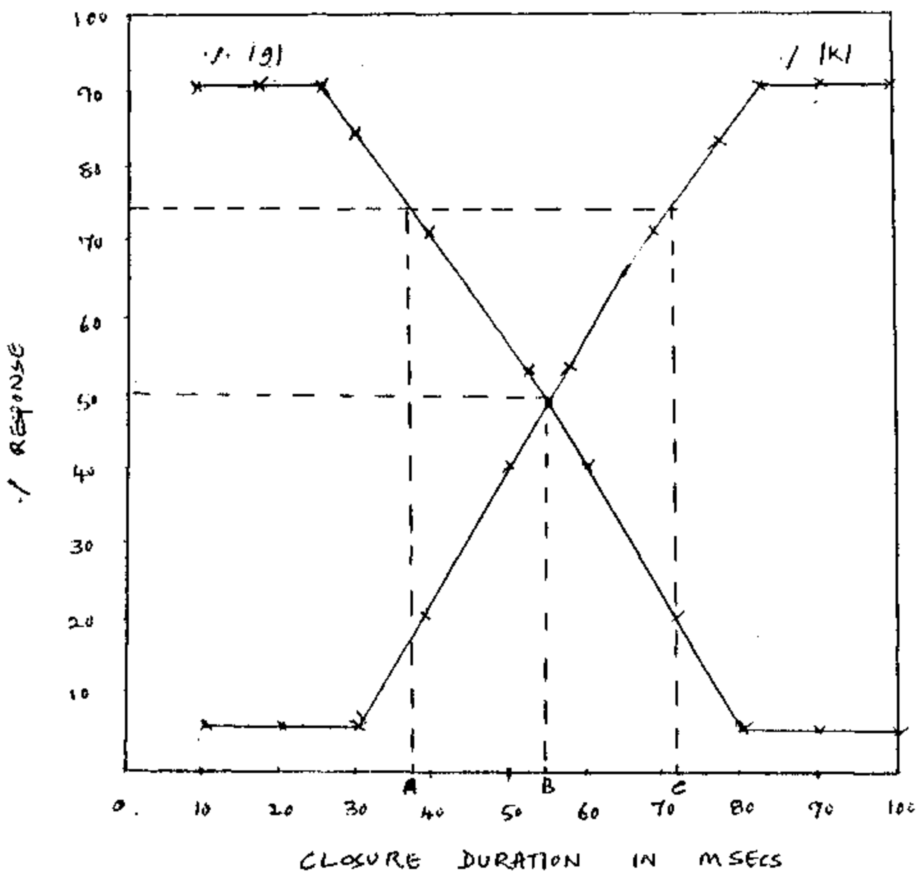

Figure 3.2: Depicts 50% crossover, Lower limit & Upper limit.

RESULTS

SPEECH PRODUCTION:

Mean VOT: Voiced stops were characterized by lead VOT and the voiceless stops were characterized by lag VOT. Among the voiced stops consonants, velar /g/ had the longest VOT followed by dental /d/ and bilabial /b/. However, in the age range of 4-5 years, dental had the longest VOT followed by velar and bilabial, and in 6-7 years age range the longest VOT was exhibited for bilabial followed by dental and velar. Among the voiceless cognates, velar /k/ had the longest VOT followed by dental /t/ and bilabial /p/ in all the three age groups. When the mean VOT's for the voiceless cognates were compared between the three age groups, children in the age group of 5-6 years exhibited longest mean VOT value followed by children in 4-5 years and 6-7 years for /k/ and /t/, for bilabial /p/, children in 4-5 year age group exhibited shorter VOT than chiIdren in 6-7 year age group. There was no linear developmental trend. However, when the mean VOT values of 4-5 year old children were compared with those of 6-7 year old children, it was observed that there was a decline in the VOT values. When the average VOT's of the voiceless stops in children were compared with those of adults, children exhibited longer lag VOT's and for the voiced cognates, children exhibited shorter lead VOT's. It appears that the children use long lag for voiceless stops and short lead for voiced stops and adults use short lag and longer leads for voiceless and voiced stops respectively.

Table 3.3 depicts the mean VOT in various age groups.

Age	k	g	t	d	p	b
4-5	37	- 66	21	- 74	15	- 56
5-6	53	- 76	31	- 69	21	- 59
6-7	36	- 41	21	- 47	18	- 54
Average	42	- 81	24	- 63	18	- 56
Adults	33	- 80	15	- 85	19	- 85

Table 3.3 : Mean VOT for children (4-7 yrs) & adults.

Range of VOT : The range of VOT decreased from the age of 4 years to the age of 7 years for alI stops except for /d/. In general, the VOT range was more for voiced stops than for voiceless stops. Among the voiceless stops, velar /k/ had the highest range followed by dental /t/ and bilabial /p/. In children in the age of range of 4-5 years, 5-6 years velar /K/ had the highest range. In 6-7 year age group children, dental /t/ had the highest range. Among the voiced stops, velar /g/ had the highest range and no pattern with respect to place of articulation was evident and when the data of children was compared with that of adults, it was observed that the range of VOT decreased in adults (except for /g/). Table 3.4 shows the range of VOT.

Age	k	g	t	d	P	b
4-5	38	73	31	46	32	65
5-6	34	40	27	36	18	50
6-7	22	36	25	58	10	46
Average	31	56	27	46	20	53
Adults	18	66	11	34	11	44

Table 3.4: VOT range across children (4-7yrs) and adults.

Lower and upper limits: The lower limit of VOT increased and the upper limit of VOT decreased from 4-7 years of age and velar /k/ exhibited the highest upper limit and lower limit followed by dental /t/ and bilabial /p/. Similar pattern was exhibited by adults. However, in the voiced stops, no specific pattern was observed. When upper limit and lower limit were compared between children and adults, in adults, the upper limit and the lower limit decreased in voiceless stops and both increased for voiced stops (Table 3.5 & 3.6).

Age	k	g	t	d	p	b	1
4-5	58	- 102	42	- 113	- 37	- 93	
5-6	68	- 103	46	- 96	- 35	- 88	
6-7	46	- 72	38	- 79	- 18	- 82	
Average	57	- 89	35	- 72	- 30	- 87	
Adults	45	-126	21	- 105	- 17	- 112	

Table 3.5 : Lower limit of VOT (msec).

Age	k	g	t	d	p	b
4-5	20	- 35	11	- 67	6	- 29
5-6	34	- 63	19	- 60	17	- 38
6-7	24	- 36	13	- 21	8	- 36
Average	26	- 44	14	- 49	10	- 34
Adults	27	- 60	10	- 71	6	- 68

Table 3.6: Upper limit of VOT (msec)

S Ratio: In general, it was observed that no specific developmental trend was evident. However, when the data of children in 4-5 years was compared with those of 6-7 years. it was found that s-ratio decreased from 4 to 7 years of age. Larger S-Ratio was depicted by velar followed by bilabial and dental. However, in adults the S-ratio was highest for velar followed by dental and bilabial (Table 3.7).

Age	k/g	t/d	p/b
4-5	103	95	71
5-6	129	100	80
6-7	77	68	72
Average	103	100	104
Adults	113	87	74

Table 3.7: 'S' ratio for children and adults.

Also a larger 'S' ratio was exhibited for all places of articulation by children in the *age* group of 5-6 *years.*

Comparison of 'S' ratio between children and adults reveal that the adults had shorter S-ratios compared to children for dental and bilabial.

SPEECH PERCEPTION:

50% cross over : In general, the cross over from voiced to voiceless cognate occurred at lead VOT and in children, the shift occurred earlier for velar followed by bilabial and dental or in other words the cross over was earlier for those phonemes uttered at the extreme ends of the oral tract. The number of subjects who reached 50% cross over and the mean of 50% cross over points for the k-g, t-d and p-b continuum are in Table 3.8 & 3.9 respectively.

Continuuml	4-5	5-6	6-7	7-8	8-9	9-10	Adults
k-g	4	2	1	4	2	5	5
t-d	3	3	2	6	6	5	6
p-b	3	2	1	5	3	5	6

Tab Ie 3 - 8: Number of subjects who reached 50 % cross over.

Stimuli	4-5	5-6	6-7	Avg	Adults
gadi/kadi	**- 17**	**- 30.1**	**- 10**	**- 19**	**- 18.6**
dada/tada	**- 28**	**- 6.5**	**- 8.5**	**- 14.3**	**- 18**
badi/padi	-12	-13.9	-26	-17.3	-5.4

In adults, the shift from voiced to voiceless cognate was earlier in velar followed by dental and bilabial place of articulation. In all the age groups the shift was in the lead region of VOT continuum. The shift occurred earlier for the velar place of articulation both in the age group of 5-6 years and in adults. But the shift was earlier for the dental in 4-5 age group and for bilabials in 6-7 year age Fig. 3.4 shows the identification functions . When the mean 50% cross over values of the 4-7 years were compared with that of adults, children exhibited earlier cross over than adults for velar and bilabial place of articulation.

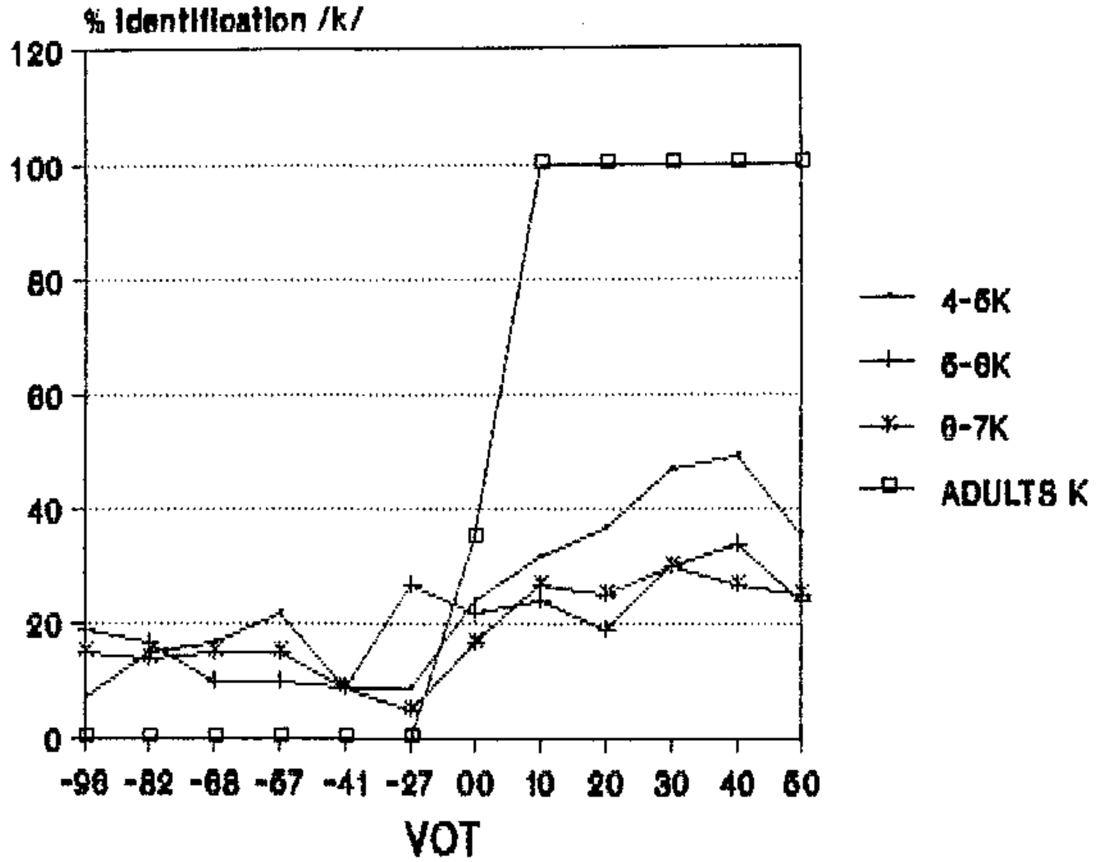

Fig 3.4a: Percent Identification of /k/ for VOT

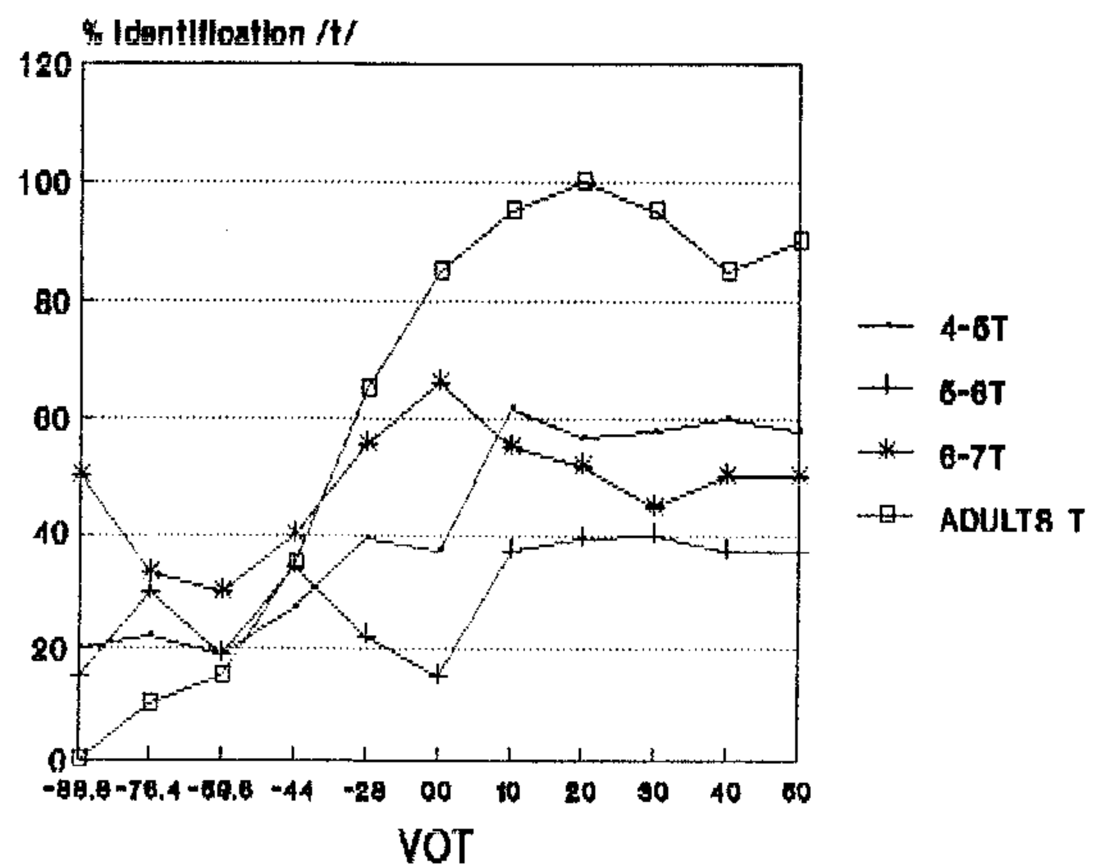

Fig 3.4b; Percent Identification of /t/ for VOT

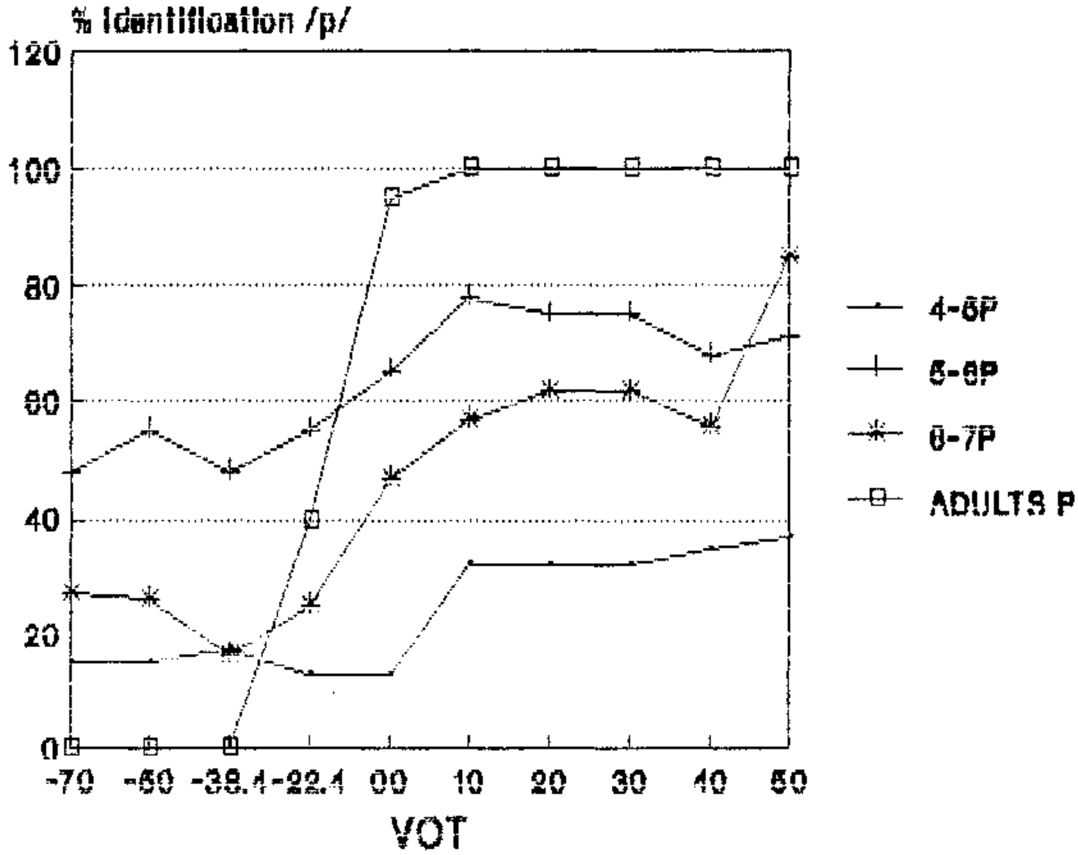

Fig 3.4e: Percent Identification of /p/ for VOT

Lower limit: When the lower limit between the age groups were compared, it was observed that the shift from voiced stops to its voiceless cognates started occurring in the lead time of the VOT continuum for all the age groups for all places of articulation (Table 3.10).

The 6-7 age group children approximated the adults in that the limit was highest for dental followed by velar and bilabial. But the shift occurred much earlier in 5-6 year age group children. The lower limit was higher for the dental place of articulation in the age range of 6-7 years and adults and for bilabial place of articulation in the age range of 5-6 years.

Stimuli	4-5	5-6	6-7	Avg	Adults
gadi/kadi	- 44	- 49.5	- 18	- 37.3	- 37
dada/tada	- 32	- 34	- 63	- 43	- 43
badi/padi	- 5	— 65	- 3.9	- 24.6	- 36

Table 3.10: Lower limit of phoneme boundary

Upper limit : Comparison of upper limits revealed that the upper limit for 5-6 year age group children fall in the lag region of VOT continuum for all places of articulation. But the same was not true for the other two groups since only for bilabials in 4-5 year age group and for velar in 6-7 years, the upper limit was in the lag region and for dental it was in the lead region of the VOT continuum. In 4-

5 year age group the upper limit decreased in the order of bilabial, velar and dental, where as in 5-6 year age group, it was in the order of bilabial, velar and dental and in 6-7 year age group, the order was velar, bilabial and dental (Table 3.11). Thus, no consistent pattern was observed across the age groups when upper limits were compared. The comparison of the upper limit between adults and children revealed that the shift from voiced to voiceless percept occured earlier for dental place of articulation in children.

Stimuli	4-5	5-6	6-7	Avg	Adults
gad1/kadi	- 2	- 5.3	+ 2	- 1 .8	- 2
dada/tada	- 5	- 15.5	- 22	- 14.8	8
badi/padi	18	- 5	- 6.5	-2.1	-2.8

Table 3.11: Upper limit of the phoneme boundary of 4-7 years children and adults.

Boundary width: The boundary width decreased from velar to bilabial place of articulation in 4-5 and 6-7 year age group. In 5-6 year age group, the boundary width decreased from bilabial to dental place of articulation. Though there was no linear developmental trend, the boundary width decreased from 4 to 7 years of age (Table 3.12).

Continuum	4-5	5-6	6-7	Avg	Adults
k-g	42	45	16	34	25
t-d	27	19	41	29	26
p-b	13	60	2.6	25	13

Table 3.12: Boundary width for children and adults

A comparison of the boundary width between children and adults revealed that the boundary width decreased in adults when compared to children.

DISCUSSION

SPEECH PRODUCTION:

The results revealed several findings of interest. First of all while voiced stops were characterized by lead VOT, voiceless stops were characterized by lag VOT. This is in consonance with the results of earlier studies in children by Zlatin and Koenegsknecht (1976) and in adults by Lisker & Abramson (1964), and Shukla (1989), Sridevi (1990) in kannada. In voiceless stops lag VOT was observed, since during the production of voiceless stop, voicing starts when a transglottal pressure drop sufficient to initiate voicing is developed after the burst release. (Mueller & Brown 1980).

Second, VOT for voiceless stops lengthened as the place of articulation moved backward in the oral cavity. VOT varies inversely with the rate at which oral release gesture is made (Summerfield and Haggard, 1977). The duration of the movement of the articulation that forms the closure Is greatest for the tongue body, less for the tongue tip and least for the lips (Fant, 1960, Stevens & Klatt 1974). An increase in the time taken for consonantal release leads to

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an increase in the time taken for the development of a transglottal pressure drop sufficient to initiate voicing and to an increase in VOT. Hence VOT is shortest for bilabial and longest for velar. Thus, the measure of VOT is, to a certain extent, sensitive to the place of stop consonant constriction. This is in consonance with the results of the study by Lisker & Abramson (1964 & 67), Basu (1979), Borden & Harris (1980), Shukla (1989) and in contrast to the results of the study by KushaI Raj & Nataraja (1984).

Third, VOT decreased nonlinearly from the age of 4-7 years Also, in adults VOT decreased indicating a developmental trend. This is in consonance with the results by Lisker & Abramson (1964) & Zlatin & Koenegsknecht (1976).

It is presumed that VOT decreases in adults owing to more alternate timing co-ordination of the speech mechanism and physiological maturity.

Fourth, the range of VOT decreased from the age of four years to the age of 7 years and further in adults indicating a developmental trend. It appears that as children grow, their articulation becomes more precise and hence follow more adult I ike patterns.

Fifth, in adults the lower limits and the upper limits decreased for voiceless stops and increased for voiced stops indicating that the adults have a narrower range and can differentiate the voicing contrast.

Sixth, the S-ratio increased in adults when compared to children indicating that the voicing contrast is better in adults. While adults mainly use VOT as a parameter to differentially produce voiced/voiceless stops, children may use other parameters.

Seventh, some children in the age range of 4-7 years showed lead and lag VOT for voiced stops. However, the percentage of children using lag VOT is not *very* high in this experiment. This indicates that the children can't use lag and lead VOT differentially in the earlier age group and as they learn adult like pattern a clear differentiation occurs.

Cessation of voicing was observed in children for velar and dental. Studies on aerodynamics of stop consonants (Mueller & Brown 1980) revealed that cessation of voicing in voiced stops occurs when the subglottic pressure equals that of the supraglottic pressure. The equalization of pressure can be brought about by several mechanism which may act independently or collectively. The mechanisms which either facilitates voicing are of two types (a) glottal and supraglottal articulatory adjustments and (b) internal laryngeal adjustments. In children, owing to smaller vocal tract, the pressure equalization occurs at earlier time leading to cessation of voicing.

An interesting finding of the present study was that the VOT were longer in 5-6 years old children. Several authors (Hurlock, 1968, Joseph,& Braga, 1974, Greene 1964) have reported that the age between 5-6 years is a period of transition for children. In this age range, several anatomical and psychological changes have been reported which is in turn reflected in poor performance in all the activities like writing and other skills when compared to adults. In this age, children see themselves as incompetent in comparison with adults, and they are realistically so. But their inability to always cope with the demands of adults reinforces their feelings of incompetence. In reference of their own position and in fear of progressing into the increasingly demanding adult world, children may behave in a way that might seem less mature than before, (Joseph & Braga, 1974). Also, between the age of 5-6 years, chiIdren's writing skill is reported to be slow, laborious and very poor (Hurlock, 1968). Physiologically, the change in the pitch has been reported by Negus, 1962, that is the voice of the child of 5 years loses the piping pitch of the first years and the child's speaking voice settles under the influence of the environment at a median pitch in the region of middle C, or may be 2 or 2.5 semitones higher.

SPEECH PERCEPTION:

The results indicate that the 50% cross *over* from voiced to voiceless cognate occurred in the lead VOT for children and adults. This result is in contrast with those of Lisker & Abramson (1964) & Zlatin & Koenegsknecht (1975).

An interesting result was that the 50 % cross over occurred in the lead VOT region. While it occurred in the lead region of -14.3 to -19 msec for children, adults showed the cross over between -5.4 to -18.6. A comparison of the 50 % cross over points as obtained by various studies is in Table 3.13.

Author	Year	Language	Stimuli	50 % cross over in m.sec
Yeni-Komshian et.al	1967	English	/g/	35
Lisker & Abramsom	1967	Thai	-	-20
Simon	1974	English	-	15-20
Zlatin et.al	1975	English	-	+25
Williarns	1977	English		+25
		Spanish		-4
Williams	1980	**English**	/b-p/	>15 (4-8yrs) 19 (7-10yrs) 25 (adults)
Flege & Eefting	1986	English	-	36.2
		Spanish	—	19.9
Sathya	1996	Telugu	/g-d-b/	-10 (children) -20 (adults)
Present study	1996	Kannada	/g-d-b/	-16.8 (children -10.7 (adults)

Table 3.13: 50 % cross over values as obtained by various authors.

Williams (1977) speculated that Spanish listeners give greater weight to prevoicing as a cue to voicedness than English listeners and greater weight to the presence of an audible release burst & the lack of low frequency energy immediately following it, as cues to voiceless. The finding of Williams (1977) that the category boundary between /b/ & /p/ occurred along a VOT continuum occurred around -4 msec for Puertoricans who were monolingual Spanish speakers suggest that the phonetic processing of speech may be slowly attuned to the acoustic properties of stops found in a particular language (Aslin & Pisoni,1980). Flege & Eefting (1986) imply that cross language research suggests that speakers of different languages may learn to perceive stops differently because they are exposed to different kinds of stop consonants. Further, English language environment listeners tend to identify both /b/ & /p/ as the phoneme /b/ & the prevoiced/voiced, contrast is physiologically irrelevant in English. This contrast is. perceived categorically in other languages ;- for eg- Hindi, Spanish & Thai (Burnham, Earnshaw & Clark, 1991).

Williams (1980) says that in addition to VOT there are three additional acoustic properties that vary in degree across part of the synthetic speech series. These variations are restricted to the voicing lag region of the continuum:

1. The presence, absence or varying duration of aspiration or aperiodic energy in the interval between articulatory release and the onset of voicing. The presence of aspirated formants is an acoustic property that has been demonstrated to provide a positive cue for initial voicelessness to English listeners (Winitz etal,1975).
2. The absence of periodic acoustic energy at the level of F1 during aperiodic excitation of the vocal tract referred to as first formant cutback (Liberman etal 1958). There is also evidence that the presence or absence of periodic energy in the region of F1 provides a perceptual cue for an initial contrast in voicing for English listeners (Delattre etal 1955, Liberman etal 1958 and Lisker 1975).

3. Differences in the degree and temporal extent of formant transitions under conditions of periodic excitation of the vocal tract. There is some evidence that this acoustic variable may also provide a cue for initial voicing in English (Cooper etal 1952, Stevens & Klatt 1974, Summerfield & Haggard 1974).

On examination & comparison of spectrograms of /b/ & /p/ taken for Kannada with those provided by Williams (1980) reveals that the stop consonants in Kannada are entirely different than that of English in all the three parameters listed above . Figure 3.5 presents spectrograms of /b/ & /p/ in English and Kannada.

Neither aspiration in the lag VOT region, nor F1 cutback is present. These differences in the acoustic properties of stops in English and Kannada might be reflected in the perception also with a 50 X cross over in the lag VOT region for English and lead VOT region in Kannada.

Also, while in the other studies the syllables have been synthesized using the Klatt synthesizer, in the present study waveform editing of natural stimuli has been performed. However, the waveforms are without any extraneous noise as

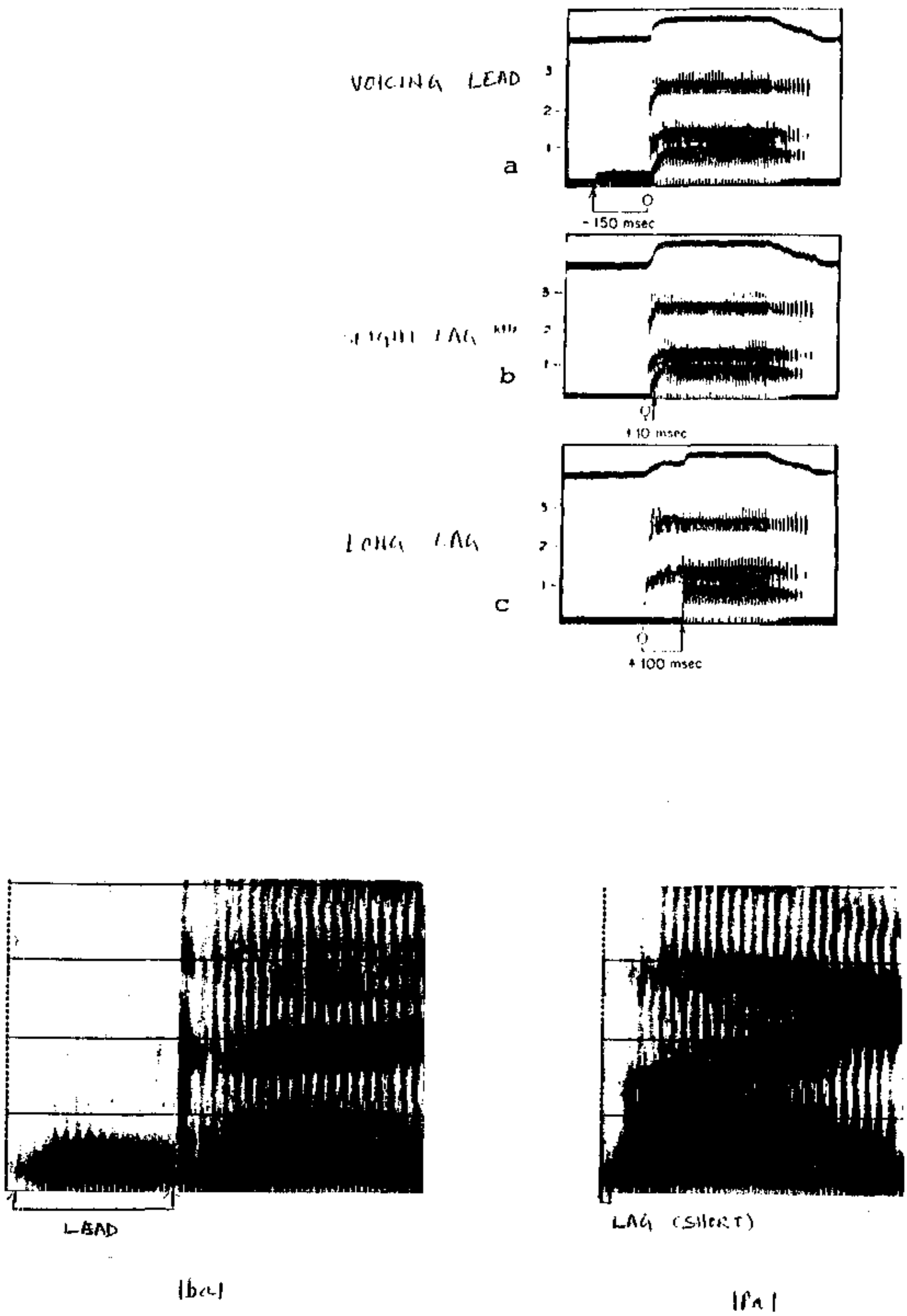


Figure 3.5: Spectrograms of /b/ & /p./ in English (Top) & Kannada.

seen on the spectrograms **and the** results are comparable to that of the earlier studies involving languages which contrast voiced and unvoiced by lead and short lag VOT.

This result that 50% cross over occurred in the lead region which is not in consonance with studies in English languages for the same reason. While in English, a contrast between lead and lag VOT's are depicted, in the present study, a contrast between lead and short lag VOT's are depicted. In 3-way or 4-way category languages like Kannada which resemble Telugu, Spanish, Thai, it appears that the crossover occurs in the lead VOT region. While in Telugu, it occurred around -10 msec in children and -20 msec for adults, in Kannada it was around -17 msec in children and -11 msec in adults, in Thai at around -20 msec (adults) and in Spanish at -4 msec (adults). While in Telugu, adults identify voiceless stops at longer VOT's than children, in Kannada adults identify voiceless stops at shorter VOT's than children.

While comparing the discrimination data obtained from adult speakers of Thai and English for synthetic bilabial stop consonants, Aslin & Pisoni (1980) comment that "the relative discriminability in the -20 msec of voicing lag is greater than in the -20 msec region of the voicing lead despite the fact that the slopes of the labelling functions for Thai subjects in these regions are very nearly identical. They propose that the smaller incidence of discrimination of VOT (and TOT) differences in the minus region of voicing lead value is probably due to the generally poorer ability of the auditory system to resolve temporal differences in which a lower frequency component precedes a higher frequency component" (for unvoiced stop and lower frequency component - voicing - precedes a higher frequency component for - burst release - for voiced stop).

Aslin & Pisoni (1980) further commenting on infant studies on VOT suggest that "The discrimination of the relative order between the onset of first formant and higher formants (Pisoni, 1977) is more highly discriminable at certain regions along the VOT stimulus continuum corresponding roughly to the location of the threshold for resolving these differences Psycho-physically. In the case of temporal order processing, this falls roughly near the region surrounding ± 20 msec, a value corresponding to the threshold for temporal order processing (Hirsh, 1959)".

Further commenting on Pisoni's (1977) experiment on TOT (Tone onset time), Aslin & Pisoni (1980) say that "two distinct regions of high discriminability are present in the discrimination functions. Evidence of discrimination of VOT contrasts that straddle the -20 and +20 msec regions of the stimulus continuum probably results from general sensory constraints on the mammalian auditory system to resolve small differences in temporal order and not from phonetic categorization.

This might be possible, as the wide differences obtained in the category boundaries for various languages varied from -4 to -20 msec (which is more than one stimulus -10 msec - along the VOT continuum). Also, in Kannada it varied from -14 to -19 msec for children and -5 to -19 msec for adults for various places of articulation. All these variations are within 20 msec.

Three views regarding the differences in perception of voicing contrast in various languages are held (Burnham et al., 1991). (1) Phonetic contrasts in languages have evolved to take advantage of the natural psycho-acoustic abilities inherent in the human auditory system rather than the other way round (Kuhl, 1978). (2) Contrasts differ in their degree of robustness or perceptual salience and (3) the more perceptually salient a particular contrast, the more likely it is to have been favored in the evolution of the world's languages (Burnham & Earnshaw, 1991). In Kannada, the contrast of voiced/voiceless unaspirated in perceptually salient which is depicted in the result that 50% cross over is occurring in the lead VOT region. It is possible that two category boundaries might be obtained if voiced unaspirated, voiceless unaspirated and voiceless aspirated are contrasted. It would be interesting to study a language like Tamil where phonemic contrast between voiced and unvoiced are not existing.

A comparison of the speech production and speech perception data (Table - 3.15) indicates no one to one relationship between production and perception. While In speech production, the voicing of stops are well contrasted with the voiced stops demonstrating lead VOT and the voiceless stops demonstrating lag VOT, in speech perception task, though children reveal abilities to discriminate between the two, children and adults identified the tokens with short lead VOT (less than 20 msec) as voiceless stops.

		k	g	t	d	p	b
VOT	Children Adults	LL LL	L L	LL SL	L L	SL SL	L L
50 % Crossover	Children Adults	L L		L L		L L	

Table 3.14: VOT type in speech production and speech perception
LL: Long lag SL: Short lag L: Lead

While in speech production task, VOT decreased from 4-7 years, in speech perception task the 50% cross over appears to shift from longer lead VOT's to short lead VOT's. Also, longer VOT's and higher 50% cross over were observed for velar in both children and adults.

Another interesting result was that the boundary width decreased from 4 to 7 years of age indicating that the children could make a finer distinction between the voiced and the voiceless cognates. A comparison of S-ratio and boundary width between children and adults (Table - 3.15) boundary width between children and adults (Table - 3.15) reveal that, in aduIts,S-ratio increases and boundary width decreases for all pairs of stop cognates. Also, this comparison indicates that children even at the age of 7 years do not attain adult like patterns. This data reflects a distinct production of voicing contrasts (high S-ratio) and a finer discrimination ability (narrow boundary widths) in adults.

		Children	Adults
k-g	S-R	103	113
	B.W.	34	25
t-d	S-R	87	100
	B.W.	29	26
p-b	S-R	74	104
	B.W.	25	13

Table 3.15: S-Ratio & boundary width in children and adults (in msec)

The data reveals a definite shift in perception from voiced to voiceless cognates for all the three continuum considered. Based on the above findings it could be concluded that VOT acts as a cue in voicing distinction in Kannada language.

Children as younger as 4-5 year age group are able to distinguish voiced/voiceless category using temporal parameter VOT. This is in consonance with the results of the study conducted by Zlatin & Koenegsknecht (1974). While testing, some subjects exhibited several kinds of responses during decision making task, even though alternate forced choice paradigm was used. Quizzical expressions were noticed particularly when the decision involved a stimulus which fall in their own boundary region. Multiple cross over points were observed more in the younger age group. During perception task, the 4 year old children displayed anticipatory behaviour. They would simply repeat the words prior or during the stimulus presentation.

These individual responses reflect the variations in maturity among children. Children in the age group of 5-6 years show entirely different responses than the children in the other age groups. The reasons for this might be that the age between 5-6 years is a transitional period as they enter the school. Several anatomical and psychological changes take place in this age (Hurlock, Joseph etal 1972, Green 1972).

EXPERIMENT II: TRANSITION DURATION

INTRODUCTION

The acoustic feature that permits identification of place of articulation must be found in the brief period of consonant production and the complex acoustic pattern produced as the articulators rapidly transit from the consonantal target positions to or from the contiguous steady state vowel. This rapid movement produces a change called a transition between the consonant and the vowel formants. The shape of the formant transitions varies with the place of articulation of the consonant and the value of the accompanying vowel.

SPEECH PRODUCTION:

Lehiste & Peterson (1961) investigated the transition durations in 1263 CV utterances & reported that the bilabials usually have shorter initial transitions than lingual consonants. Also, transition durations were longer for voiceless stop than for voiced atop.

SPEECH PERCEPTION:

A reading of the literature on the acoustic cues to stop voicing indicates that there should be nothing surprising about finding that the F1 transition plays a role. A very early paper on speech syntheses reported that "the transitions of the first formant appear to contribute to voicing of the stop consonants (Cooper, Delattre, Liberman, Borst, Gerstman,1952).

The voiced stops have a well defined transition in the first formant (as well as the second formant) of the following vowel, Whereas, the F1 transition for the unvoiced stops is essentially non-existent after the onset of voicing. The lack of formant transitions after voicing onset for the aspirated consonants indicates that the rapid movements of the supraglottal articulators (the tongue tip in the case of Fig.1) are essentially complete before the vocal cords are in a configuration appropriate for the onset of voicing. Based on synthesis experiments (Liberman, Delattre, Gerstman and Cooper, 1956), it is known in fact, that the duration of these transitions is of the order of 40 msec, or less.

These examples suggest that one of the possible cues for the voiced-voiceless distinction for stops in prestressed position is the presence/absence of a significant transition at the onset of voicing. Research findings by Stevens and Klatt (1973) for voicing perception of utterance initial stops indicate that formant transition are used as a voicing cue. Their experiments with synthetic speech compare the role of VOT and the presence or absence of a significant formant transition following voicing onset as cues for the voiced-voiceless distinction. The data indicate that there is a significant trading relationship between these two cues. The presence or absence of a rapid spectral change following voice onset produces upto 15 msec. change in the location of the perceived phoneme boundary as measured in terms of absolute VOT. One can speculate that the auditory system may be predisposed to detect the presence/absence of a rapid spectrum change as a general property of acoustic input. If that is the case the acquisition of voiced/voiceless distinction in infants may be initially conditioned by the presence/absence of this property at the onset of voicing rather than by absolute VOT.

Lisker (1975) on labeling data obtained indicate that varying VOT regularly effects a significant change in listener's judgments and that varying F1 has some effect too but this latter variation is neither necessary nor sufficient generally to shift judgments decisively from one stop category to the other. The data further suggest that the presence of an F1 rising transition after voice onset serves as a voiced stop cue not so much because of its dynamic aspect, but simply because its onset frequency is low ie. at a value appropriate to a closed or almost closed state of the oral cavity. It has been suggested that a "feature detector" responsive to a rapidly shifting F1 explains this phenomenon.

r

Subsequently, Keating and Blumstein (1978) investigated the importance of transition length in the perception of stop consonants in normal adults. Subjects participated in three tasks : labeling, discrimination and selective adaptation, in which stimuli with thwep transition lengths (45 ms, 95 ms and 145 ms) were used. Results showed that subjects discriminative performance was improved significantly within the continuum with stimuli that had transition of 95 ms duration compared to discrimination for stimuli with transition duration of 45 msec. Labeling performance was not significantly different between continua in which stimuli had durations of 45 ms and 95 ms. Further; on the selective adaptation tasks, adults shifted their category boundaries significantly in the identification of the continuum with a 45 ms duration transition even when adopters had transition durations of 95 ms and 145 ms. Keating and Blumstein (1978) concluded that the length of transition had minimal importance for the perception of place of articulation by adults. In particular the selective adaptation results were interpreted to mean that starting transition frequency as well as the target steady state values, were more important acoustic cues to listeners than were the duration of formant transition and their subsequent changes intrajectory.

Although literature has well established TD as a cue to stop consonant place of articulation in adults, developmental picture of the same is not very clear.

In a study of the perception of place of articulation in stop consonants Elliot et al. (1981) examined the labeling and discrimination performance of adults and children, 6 to 10 years of age using both natural and synthetic CV syllables. In a same-different discrimination task, children performed poorly than on labeling tasks which correlated as a function of age. Thus, Elliot et al. (1981) concluded that children's discriminating and labeling abilities were deveIopmentaI Iy different from those of adults.

In another study, Walley and Carrell (1983) synthesized stimuli in which the shape of onset spectrum and the trajectory of the formant transitions were consistent with the place of articulation of the stimulus as well as conflicting cue stimuli, in which formant amplitudes were changed so that the onset spectrum identified a place of articulation different from that specified by the formant transitions. They found that both adults and children labeled stimuli into the same phonetic categories. Further, both groups used the formant transition cues as a basis for labeling the stimuli with conflicting onset spectra and transition cues. The results of their study suggest that developmental differences between adults and children may exist only for subsets of speech stimuli, even within the place of articulation domain, or that those differences may be restricted to discrimination rather than labeling. Most important, the results indicate that the formant transitions are the important acoustic cues on which to focus in studies of developmental speech perception.

Sussman and Carney (1989) investigated normal children to see if they demonstrate increasing developmental changes in their perception of place of articulation for stop consonants with short and long formant transitions on discrimination, labeling and selective adaptation paradigm. Two sets of stimuli varying (synthetic CV syllables) along a seven step, bilabial to alveolar dimension were used as stimuli. These differed in length of the II and III formant transition (45 ms and 90 ms). Results indicated that children's discriminative abilities gradually approximated those of adults, but did not reach adult levels even at 10 years of age. Difference were not observed in the labeling task. Further, results of the selective adaptation task indicated that only the adult subjects showed a significant boundary shift for any adapting stimuli. This reflected poor auditory abilities in children. Thus, the pattern of speech perception development for children for place of articulation is a complex one with a strong auditory developmental component.

Revoile, Pickett, Pitt, Talkin and Brandt (1987) studied the use of cues to voicing perception of initial stop consonants in normal hearing and hearing-impaired children. They found that transition portions of the vowel onsets in burst less /bxd, gxd, dxd/ contained strong cues for voicing perception of /b, g, d/.

A different type of manipulation of formant transitions had been the focus of earlier developmental studies by Tallal and Piercy (1974, 1975). Using dysphasic and normal children as subjects, Tallal and Piercy studied discriminative performance for two sets of synthetic stop consonant stimuli, one with formant transition of 43 ms duration and a second with transition of 95 ms duration. Normal subjects reached criterion performance (20 out of 24 trials correct) regardless of transition length. In contrast, only two of the 12 dysphasic children reached this criterion when the stimuli had TD of 43 ms duration, and all 12 dyspha9ic subjects performed as well as their matched normal controls when the stimuli had transition of 95 ms duration. The investigators concluded that the inability to process rapidly changing stimuli was an important factor in the language disorder that the children manifested.

In the two studies conducted by Tallal and Piercy (1973, 1975) normal control showed no difference in discriminative performance between the ST and LT stimuli. They provided no specific information about possible developmental changes in discrimination, that exist in even normal children of varying ages when stimuli with short and long transition were presented.

Results of studies of children's speech perception have not provided a clear, consistent picture of the importance of formant transition length in the perception of either place/voicing of stop consonants nor have they defined a consistent developmental pattern of perception. This experiment aims at studying the developmental trend of TD in kannada speaking normal children in the age range of 4-7 years. The purpose of the current investigation is to test the importance of transition length in the perception of voicing of initial stops by normal children and adults.

METHODOLOGY

PART A: SPEECH PRODUCTION

MATERIAL: Six meaningful kannada words (kadi, gadI, tada, dada, padi, badi) with three voiceless unaspirated stop [/k/ (velar), /t/ (dental) and /p/ (bilabial)] and their voiced cognates (g, d, b respectively) in their initial position formed the material.

SUBJECTS: Six Kannada speaking normal children each in the age range of 4-5, 5-6 and 6-7 years [3 males and 3 females in each group] and six adults in the age range of 20-30 years (3 males and 3 females) were selected for the present study. All the subjects had normal speech and hearing.

METHOD: The subjects were instructed to repeat the word after the experimenter into a microphone (AKG D 1000) which was kept at a distance of 10cms from the mouth. The list of six words was randomised and iterated five times. The repetitions of all the 30 tokens of each subject were audio-recorded on to a cro2 audio-cassette.

These audio - recordings were subjected to acoustic analysis to extract the transition duration of the stop. The output of the tape recorder was connected to the auxiliary input of the DSP Sonograph Model 5500 (Kay Elemetrics) and the waveform along with the spectrogram was displayed on the dual channel of the DSP Sonograph at 8 KHz and 2 sees time interval. Transition duration was measured by referring to the waveform and the spectrogram. Transition duration was measured as the time between the onset of F2 to the steady state of F2 of the vowel for the initial CV syllables of the words.

ANALYSIS: The data was tabulated and the mean transition duration of the five trials for each word was calculated. Also, the range of transition duration and the 'S-Ratio' were computed (S-Ratio = Mean transition duration of voiced Stop Consonant Mean transition duration of voiceless Stop Consonant).

PART B: SPEECH PERCEPTION

MATERIAL: Three Voiceless stop consonants (Velar /k/, Dental /t/ & Bilabial /p/) as in the initial positions of three meaningful Kannada words (/Kadi/, /tada/, /padi/) were selected. The initial CV syllable of these words were acoustically analyzed to extract the formant frequencies 1,2,& 3 the fundamental frequencies & intensity. Using these acoustic parameters a Klatt synthesis was performed & the initial syllables were synthesized with 45 msec & 90 msec of transition duration. The Formant frequency values are provided below.

	/k/			/t/			/p/		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
At the beginning	402	1676	2127	558	1480	2362	402	1147	2303
At 45/90 msec	480	1754	2205	578	1343	2088	402	1715	2402
F0 (in CPS)	112-116			107-111			113-105		

The initial CV syllable of the words were deleted & the synthesized CV syllables were scaled & concatenated with the respective word which formed the synthetic stimuli. A total of 90 synthetic stimuli (the six synthetic stimuli along with three original signal iterated 10 times) were audio-recorded & perceptually analyzed in the same manner as in the previous experiment.

RESULTS

Mean Transition Duration : In general, the mean transition duration of the voiceless stop was longer than that of the voiced stop. Among the stops voiceless bilabial & voiced velar had longer transition durations & dental had shorter transition durations. However, T test showed no significant difference between the mean duration of voiced & voiceless stops. Table 3.16 shows the mean transition duration.

Age in Years	k	t	P	Avg	g	d	b	Avg
4-5	**13.7**	**13.7**	14.6	**14.0**	15.3	**12.5**	15.0	**14.3**
5-6	16.0	16.0	17.0	16.3	16.0	13.0	16.6	15.2
6-7	14.8	14.1	14.8	14.6	15.7	12.3	14.5	14.2
Average	14.8	14.6	15.5	15.0	15.7	12.6	15.4	14.6
Adults	19.0	16.6	23.6	19.73	20.3	20.1	21.6	24.0

Table 3.16 : Mean transition duration of stops.

The transition duration of the voiceless stop increased from 4 - 7 years though not significantly. No developmental trend was noticed in case of voiced stop. Also, children in the age group of 5-6 years showed longer transition durations when compared with those in the other age groups. T test showed significant difference between the mean transition duration of various stop as in Table 3.17

Age in Years	VD vs VL	k vs t	k vs p	p vs t	g vs d	g vs b	b vs d
4-5							S
5-6					**S**		**S**
6-7					S		S
ADULTS			S	S			S

	4-5 vs 5-6	5-6 vs 6-7	14-5 vs **6-7**	4-5 vs **A**	5-6 vs A	6-7 A
VL Stops	S	S	**-**	**S**	S	S
WD Stops	S	S		**S**	S	S

Table 3.17 : Significant difference between the transition duration of various stop consonants.

S = Significant difference is present
A = Adults

When the data was compared with that of adults, it was noticed that the transition duration in adults was longer than that of children & it was longer for voiced than for voiceless. No child, even at the age of 7 years achieved adult like pattern. Among adults, bilabials exhibited longer transition durations & dental had the shortest transition durations.

Range of transition duration : The range of transition duration was more in voiceless stop among children & more in voiced stop in adults. Bilabials exhibited greater range of transition duration. Also, when the range of transition duration was compared to that of adults, adults always had longer range of transition duration than children. Table 3.18 shows the range (Highest - Lowest) of transition duration.

Age	k	t	p	Av	g	d	b	Avg
4-5	18	19	25	21	12	16	23	17
5-6	15	23	22	20	24	14	23	20
6-7	15	17	19	17	19	16	21	19
Average	16	20	22	19	18	15	22	18
Adults	26	21	28	25	30	26	23	26

Table 3.18 : Range of transition duration

Lower Limit : There was no difference between the lower limit of the voiced & the voiceless stops. While dental exhibited shorter lower limits, bilabial/velar exhibited longer lower limit. No increase or decrease in the lower limit of transition duration across the age was noticed. Comparing the data of children with adults revealed that adults had longer lower limit & significant difference between the lower limit of children and adults existed. Table 3.19 depicts the lower limit.

Age	**k**	**t**	**p**	**Avg**	g	d	b	Avg
4-5	9.6	9.5	10.2	10.0	12.2	8.0	9.8	10.0
5-6	12.0	11 .0	13.0	12.0	11 .0	10.0	12.0	11 .0
6-7	**11.1**	9.5	9.5	10.0	11.8	8.3	10.0	10.0
Average	10.9	10.0	10.9	10.6	12.0	8.8	10.6	**10.5**
Adults	14.0	12.0	19.0	15.0	14.0	13.0	17.0	15.0

Table 3.19: Lower limits of transition duration (msec)

Upper Limit : No significant difference between the upper limit of voiceless & voiced stop was observed. Velar & dental had the shorter upper limit among the voiceless & voiced 9top respectively. Bilabials exhibited the longest upper limit. The upper limit decreased from 4 years to 7 years of age indicating that the speech production was finely tuned as the age progressed.

When the data was compared with that of adults, it was observed that the upper limit of transition duration was longer in adults. Table 3.20 shows the upper limit for transition duration.

Age	k	t	P	Avg	g	d	b	Avg
4-5	18.0	22.0	25.0	21.6	25.0	22.0	26.0	24.3
5-6	21.6	22.0	22.5	22.0	21.8	16.0	24.0	20.6
6-7	20.0	19.0	22.0	20.0	21.0	16.0	20.0	19.0
Average	19.9	21.0	23.2	21.2	22.6	18.0	23.3	21.3
Adult3	25.0	25.0	31.0	27.0	26.0	27.0	29.0	23.3

Table 3.20: Upper limit of transition duration (msec)

S Ratio : S Ratio was very low indicating that the transition duration may not be used to separate voicing. The S Ratio is depicted in Table 3.21.

Age	k/g	t/d	p/b
4-5	1.8	2.7	1.7
5-6	1.5	3.2	4.3
6-7	2.0	3.0	2.3
Average	1.8	3.0	2.8
Adults	2.3	3.0	3.3

Table 3.21: S-Ratio for the transition duration of voiced & voiceless stop.

SPEECH PERCEPTION :

Table 3.22 depicts the number of subjects who showed the change in the percept. As the no: of subjects who depicted a change in the percept was very low, no measures were done. The results of this experiment indicated[1] that the transition duration was not a cue for voicing of stop consonants in the initial position in kannada.

Continuum	4-5	5-6	6-7	7-8	8-9	9-10	Adults
k-g	0	0	0	3	2	2	1
t-d	1	1	2	2	1	0	1
p-b	0	0	0	1	1	1	2

Table 3.22: Number of subjects who reached 50 % cross over.

DISCUSSION

The results revealed that the voiceless stop had longer transition durations than the voiced though not significantly & adults exhibited longer transition durations compared to children. This is to be expected as adults have bulkier articulators which will take longer time to move from rest to the target position.

Among the stops, Dental had the shortest transition duration. This is in contrast with the results of Lehiste & Peterson, (1961) who reported shorter transition duration for bilabial consonants when compared to lingual consonants. In the production of the dental, the tip of the tongue is involved & the back of the tongue & the lips are involved in velar & bilabials respectively. The back of the tongue & the lips are bulkier articulators compared to the tip of the tongue & hence will take longer time to move from rest to the target position, the result of which is evident in longer transition durations.

Some developmental trend was noticed in the upper limit of transition duration. The upper limit decreased from 4-7 years of age. This indicates that the children learn to fine tune the temporal feature transition duration for stop. Also, no child, even at the age of seven years, achieved the adult pattern for transition duration.

To conclude, it appears that children & adults do not use transition duration to differentiate voicing in stop. However, the place of articulation is clearly depicted in the formant transitions. In the CV combination, while the velar exhibited falling F2 & raising F3, dental (when /a/ was the following vowel) exhibited falling F2 & F3, and the bilabials exhibited raising F2 & F3. This suggests that the direction of the transition would be very important for the differentiation of the place of articulation.

CHAPTER IV

VOICING CUES TO MEDIAL STOPS

CLOSURE DURATION AS A CUE TO STOP CONSONANT VOICING

Closure duration is the interval of stop closure indicating the time for which the articulators are held in position for a stop consonant. Fig.4.1 depicts the closure duration for voiced and voiceless stop consonants.

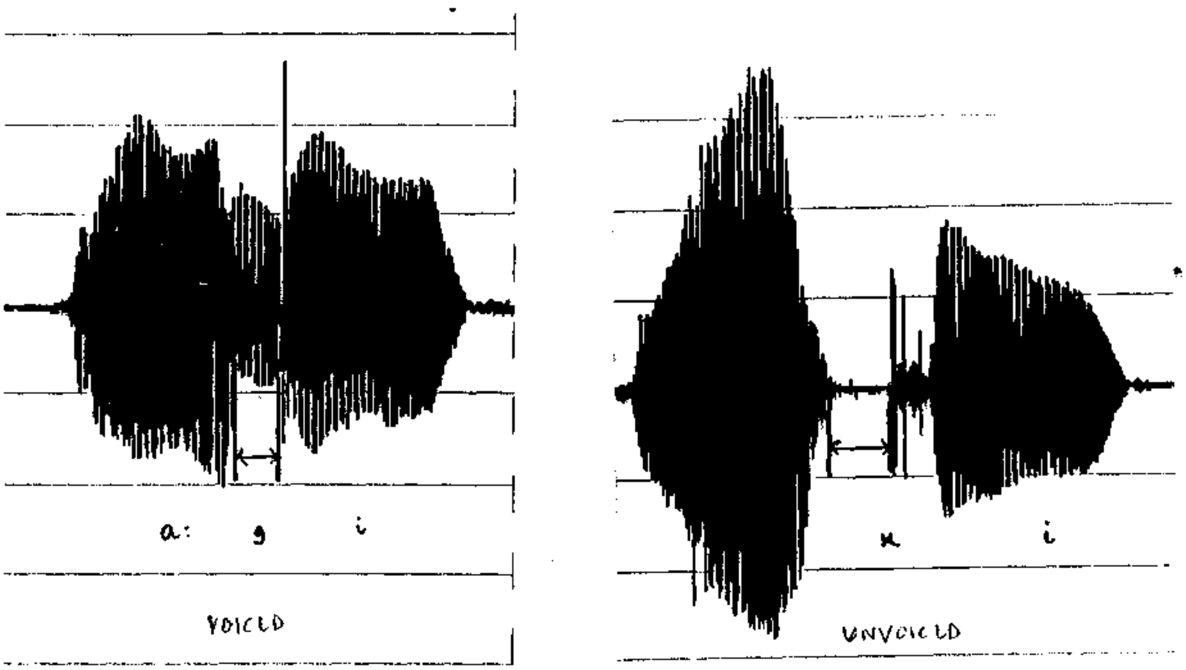


Figure 4.1: Waveforms depicting closure duration of voiced & voiceless stop consonants.

SPEECH PRODUCTION:

Lisker (1957) concluded that the closure durations of voiced stop consonants were shorter than those of the voiceless. In Kannada also the voiced stop consonants have shorter closure duartions than the voiceless (Savithri, 1986)

SPEECH PERCEPTION:

There are a number of the studies that have realized the importance of closure duration as an important cue to voicing in adults. In children this cue has been dealt in single cue and multiple cue condition.

In adults, CD has been found to cue voicing, place of articulation and manner of articulation. Also, it has been reported to trade with spectral cues. While Lisker (1978), Price and Lisker (1979), Lisker and Price (1979), Port (1980), Raphael (1981), Price and Simon (1984), Usha Rani (1989), Vinay Rakesh (1990), CazaIs and Palis (1991) studied CD as a cue to voicing, Fischei—Jorgensen (1979), Repp (1984) studied the effect of varying CD on the perception of place of articulation. CD as a cue to stop manner has been reported by Dorman et al. (1979), Bailey and Summerfield (1980), Fitch et al. (1980) and Datta (1989). Port (1979) considers CD to trade with spectral cues for the place of articulation.

In children, no study using CD in a single acoustic cue dimension has been carried out. However, two perceptual developmental study on CD have been carried out in the Indian context.

Shanthi, Nandini and Savithri (1992) studied the importance of CD as a cue to place and manner of articulation of the velar and dental Stop Consonants in Kannada. Samples of two Stop Consonants /d/ and /g/ were obtained from the words /a:ga/, /i:ga/ and /adu/ as uttered by Kannada speaking children in the age range of 5-8 years. The closure duration of Stop Consonants in each word was systematically reduced and 47 stimulus with varying closure duration were synthesized and recorded. These stimuli were presented to 4-11 year old normal children for perceptual evaluation. The subjects had to identify labels as a response in a forced choice paradigm. The results indicated that CD was a cue for the place and manner of articulation in Kannada. Reduction in CD brought about a change in place of articulation first and with further reduction there was a change in the manner of articulation. For all tokens of /g/ except the token of /i:ga/ with continuous voicing during closure and for all tokens of /d/, this trend was observed. For the token of /i:ga/ which had continuous voicing during closure, the percept did not change to place/manner across the age groups. An important finding was that a shift in category boundary from velar to either Dental or retroflex place of articulation in 4-5 year old occurred at a longer CD values than that of 10-11 years old. The observation that at reduced CD, retroflex was perceived, was in concurrence with the production data. However, in tokens with cessation of voicing of /i:ga/, there was no change in place and manner across the age groups even at minimum CD. This could be attributed to the fact that this token was produced with a very short CD (25 msec).

Secondly, the /d-r/ category was observed at very short CD. Third, other responses like /y/, /d/, /h/ were also obtained for /g/ and /t/ for /d/. The second formant of/i/ and second formant of /y/ and /I/ are closure and hence a reduction in CD of /g/ in tokens of /i:ga/ would bring about proximity of */i/* and /a/ to give a percept of semi vowel /y/ or /l/. The results of this study partly support the notion of a relation between production and perception data. Also,a developmental trend though not consistent was noticed across age groups for both place and manner.

Sathya (1992) studied the development of CD as a cue to voicing of stop consonants (p, t, t, k) in 3-6 year old Kannada speaking children. Also,the effects of linguistic syllabic boundaries and place were studied for four medial Stop Consonant /k, t, t, p/ in meaningful bi and tri syllabic Kannada words. Totally 81 synthetic stimuli varying in CD were presented to ten normal Kannada speaking children each in the age range of 3-4 , 4-5, & 5-6 years.

The results obtained revealed that at short CD voiced percept was identified and at longer CD voiceless percept was identified. As the age increased 50% crossover value reduced. Retroflex required shorter CD than velar, labial, dental. The results revealed that CD operated as a cue for voicing of stop consonants in children 3-6 years old. Also, perception was not complete at 6 years of age.

Though, these studies throw some light on the developmental trend, further developmental research (> 6 years) directed specifically to co-vary multiple acoustic parameters will be enlightening with respect to possible changes in the relative or combined strength of acoustic parameters as perceptual cues for voicing in Kannada and other Indian languages. In this context the present experiment aims at determining the development of CD in Speech Production & the strength of CD as a voicing cue to medial stop consonant voicing in Kannada language.

METHODOLOGY

SPEECH PRODUCTION

MATERIAL : Four voiceless unaspirated Stop Consonants [/k/ (velar), /t/ (retroflex), /d/ (dental), and /p/ (bilabial)] & their voiced cognates [g, d, d, & b respectively] in the inter-vocalic position of eight meaningful Kannada words formed the material (/a:k«/, /a:g*/, /a:ta/, /a:dji/, /a:ta/, /a:da/, /a:pa/, /a:ba/).

SUBJECTS : Six Kannada speaking normal children each in the age range of 4-5, 5-6 & 6-7 [3 males and 3 females in each age group] and six adults between 18-25 years were selected for the present study. All the subjects had normal speech and hearing within 15 dB HL.

METHOD : The subjects were tested individually and they were instructed to repeat the word after the experimenter into a Microphone (AKJ) which was kept at a distance of 10 cms from the mouth. The list of eight words was randomised and iterated five times. The repetitions of all the 40 tokens of each subject were audio-recorded on to Cro2 audio-cassettes.

These audio-recordings were subjected to acoustic analysis to extract the closure duration of the stop consonants. The o/p of the Tape recorder was connected to the auxiliary i/p of the DSP Sonograph model 5500 (Kay Elemetrics) and the wave form along with the spectrogram was displayed on the dual channel of the DSP Sonograph. Closure duration was measured from the wave form and Spectrogram. It was measured as the duration between the offset of formant frequencies F1 & F2 for the initial vowel and the onset of burst for the Stop Consonant. The data was tabulated and the mean closure duration of the five trials for each word was calculated. Also, the range of closure duration and the S-Ratio were computed (S-Ratio = Mean Closure duration of voiceless Stop Consonant Mean Closure duration of voiced Stop Consonant).

SPEECH PERCEPTION

MATERIAL: Four voiceless stop consonants in the medial position (velar /k/, retroflex /t/, dental /t/ and bilabial /p/) were selected for this experiment (Table 4.1). Four meaningful bisyllabic Kannada words /a:ki/ /a:ti/ /a:ta/ and /a:pa/ with these Stop Consonants in the medial position were considered. These words formed a minimal pair with a change from unvoiced Stop Consonant to voiced Stop Consonant.

Phoneme	Bisyllabic Voiceless	words Voiced
/k/	a:ki	a:gi
/t/	a:ti	a:di
/t/	a: ta	a: da
/p/	a: pa	a : ba

Table 4.1: Words selected for the experiment.

An adult Kannada native normal speaker aged 23 years served as the subject. These words with voiceless Stop Consonant in the medial position were written one each on a card and the data was acquired and digitized as displayed on the VSS-DISPLAY in the same manner as in Experiment-1.

The original CD was measured using the wave form Display of VSS-SSL for each of the stop consonants. The synthetic tokens of CD were generated using the wave form editing procedure in Display of VSS-SSL software. The original CD was truncated in terms of 10 msec, steps from the burst and until the CD was almost removed (less than 10 msec.). The CD values of the stimulus generated are in Table 4.2.

CD Stimulus	/k/	/P/	/t/	/t/
Original SO	104	80	120	86
S1	94	70	110	76
S2	84	60	110	66
S3	74	50	90	56
S4	64	•40	80	46
S5	54	30	70	36
S6	44	20	60	26
S7	34	10	50	16
S8	24	0	40	6
S9	14	-	30	-
S10	4	-	20	—
S11	-	-	10	—
S12	-	-	0	-
Total	110	90	120	90

Table 4.2: Stimuli with CD edited.

Each word with its synthetic tokens was considered as a test and within each of the four tests, the tokens were randomized and iterated 10 times. These synthetic tokens with truncated CD in four places of articulation were then audio - recorded on a metallic cassette with an ITI of 3 sec. and ISI of 5 sees using the batch program. This served as the test material for CD which consisted of a total of 410 stimuli. An example of original CD and truncated CD 13 presented in the figure-4.2.

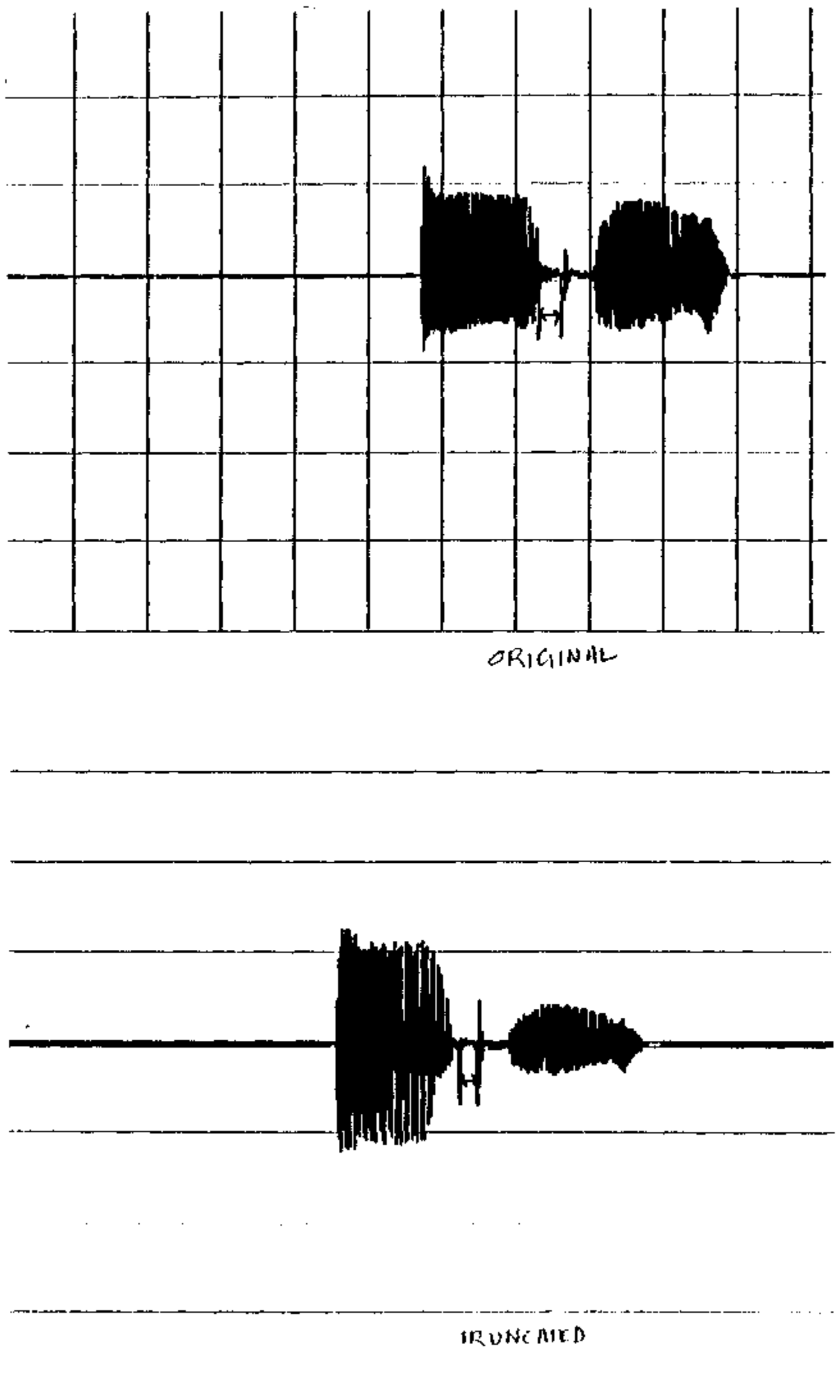


Figure 4.2: Waveform depicting original & truncated CD.

RESULTS

SPEECH PRODUCTION:

In general, it was observed that the voiceless stop consonants were longer than the voiced stop consonants. Among the voiceless stop consonants, the retroflex was the longest in all the age groups and the dental was the shortest. However, the same was not true for the voiced stop consonants, while in the age range of 4-5 years and 5-6 years the voiced bilabial was the longest, in the age range of 6-7 years the velar /g/ was the longest. The voiced retroflex /d/ was the shortest of all the speech sounds. Table 4.3 depicts the mean closure duration of stop consonants.

	Voiceless				Voiced			Average	
	4-5	5-6	6-7		4-5	5-6	6-7	Voiceless	Voiced
V	159	190	158	V	86	125	132	169	114
R	162	197	159	R	53	123	90	173	89
D	135	177	139	D	77	124	94	150	98
B	150	176	159	B	91	137	105	161	111
Avg:	151	185	151		76	127	105	163	103

Table 4.3: Mean Closure duration of stop consonants.

The range of closure duration is given in Table 4.4. The range of Closure duration did not follow **any** specific pattern for the place of articulation. The closure duration range, in general, was more for voiceless stops than for the voiced stops. Among the voiceless stops, the retroflex /t/ had the maximum range and the dental /t/ had the minimum. Among the voiced stops, the velar /g/ had the minimum. maximum range and the bilabial /b/ had the minimum.

	Voiceless				Voiced			Average	
	4-5	5-6	6-7		4-5	5-6	6-7	Voiceless	Voiced
V	53	78	76	V	54	89	57	69	66
R	44	105	67	R	36	52	44	72	44
D	33	84	44	D	37	67	75	53	59
B	47	64	68	B	49	16	39	59	34
AVG	44	60	63		44	56	53	63	50

Table 4.4: Range of Closure duration of stop consonants.

It appears that both the closure duration and the range of closure duration increase in the age range of 5-6 years. Though there was no linear increase in closure duration and it's range, when the data of 4-5 years old children were compared with that of 6-7 years old children, it appears that the closure duration and its range increased from 4 to 7 years of age.

The lower limit and upper limit for stop consonants are given in the table 4.5 & 4.6. Both the lower limit & the upper limit were higher for the voiceless consonants when compared to the voiced consonants. It was noticed that the velar / bilabial had higher upper limit and higher lower limits & the retroflex / dental had lower upper & lower limits. Also, the limits increased in the age of 5-6 years old children.

	Lower Limit voiceless				Lower Limit voiced		
	4-5	5-6	6-7		4-5	5-6	6-7
V	139	155	119	V	62	75	105
R	139	143	114	R	46	76	75
D	118	139	115	D	58	91	75
B	126	143	120	B	66	101	83

Table 4.5 : Lower limit of closure duration.

	Upper Limit voiceless				Upper Limit voiced		
	4-5	5-6	6-7		4-5	5-6	6-7
.v	191	233	195	V	116	164	162
R	183	248	181	R	82	128	120
0	151	223	-	D	95	15R	149
B	173	207	187	B	115	117	129

Table 4.6: Upper limit of closure duration.

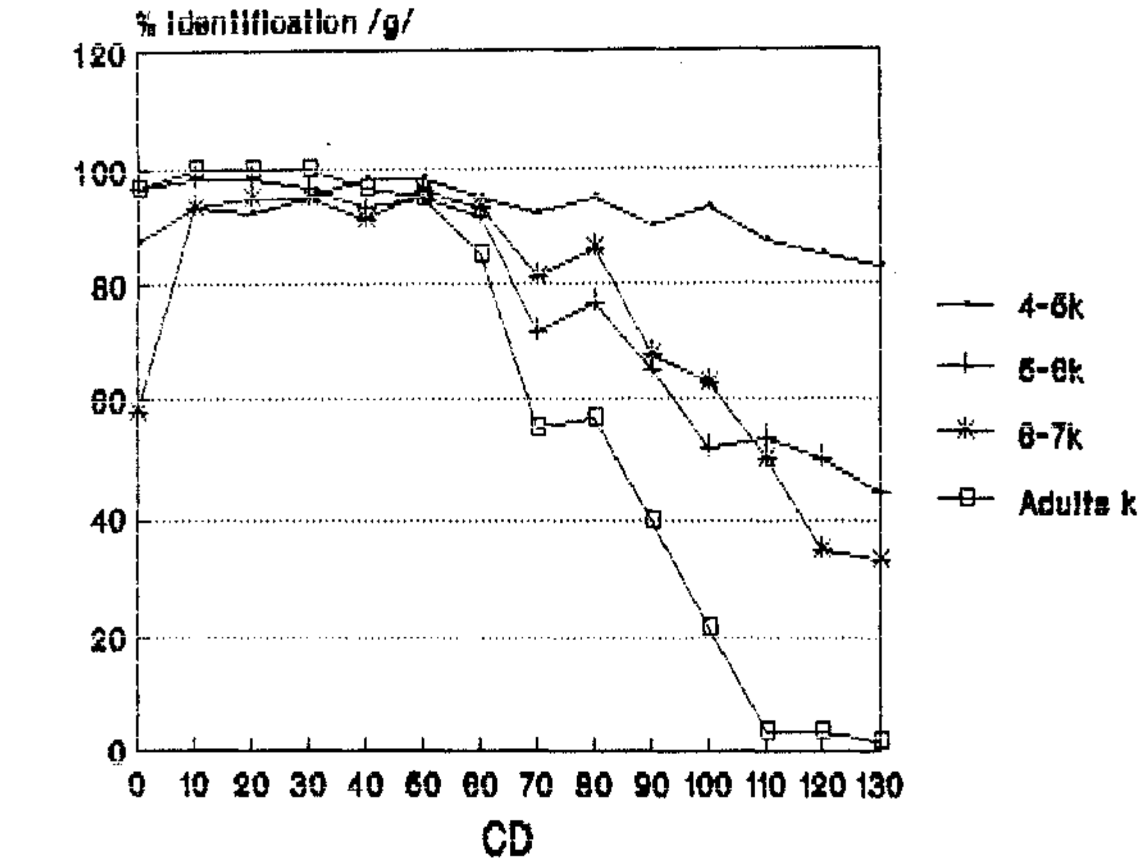
	4-5	5-6	6-7	Average Children	Average Adults
V	73	67	23	54	45
R	112	72	68	84	60
D	58	50	45	51	54
B	57	39	55	50	13

Table 4.7: S-Ratio of stop consonants.

Table 4.7 depicts the S-Ratio. The results indicate that the S-Ratio decreases from 4-5 years to 6-7 years and further in adults. The retroflex had the maximum S-Ratio indicating a good category separation between voiced and voiceless consonants in that place of articulation.

SPEECH PERCEPTION:

At shorter closure durations, children perceived voiced stop consonants and at longer closure durations, they perceived voiceless stop consonants. The 50% cross over was high for the retroflex (t-d) in children in the age range of 5-6 and 6-7 years.



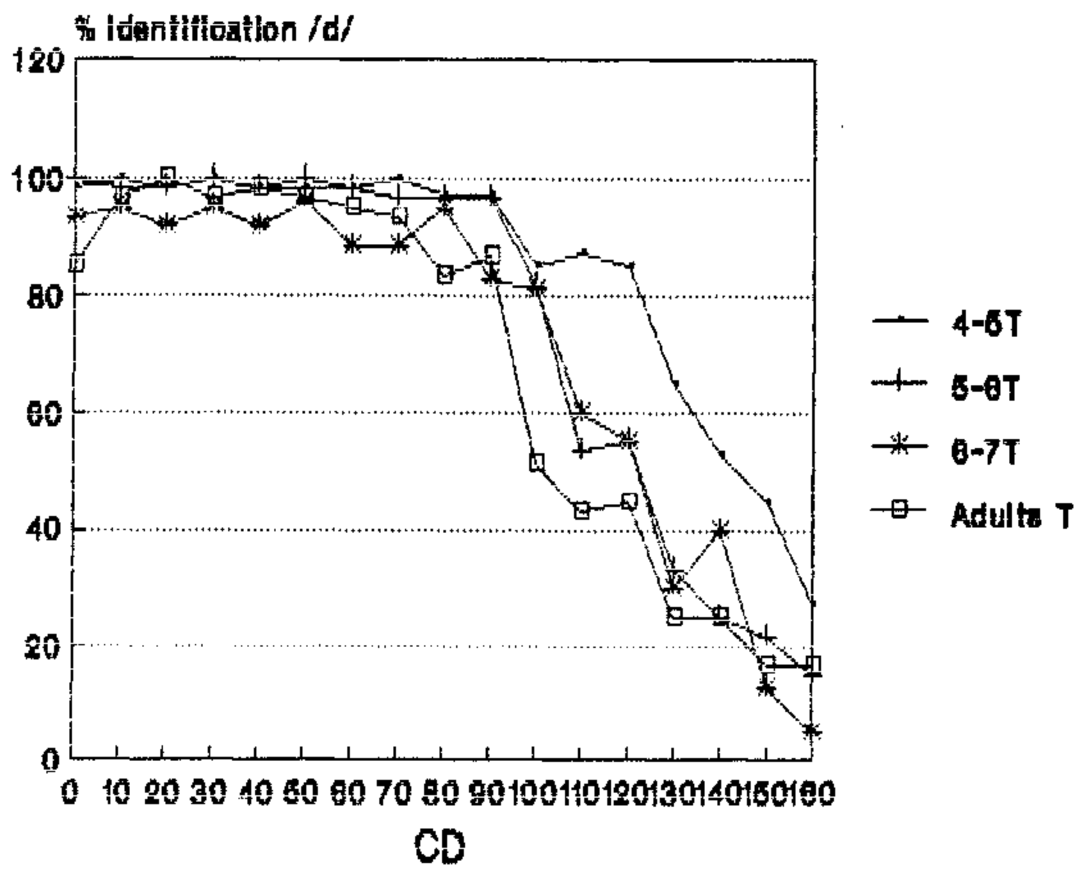
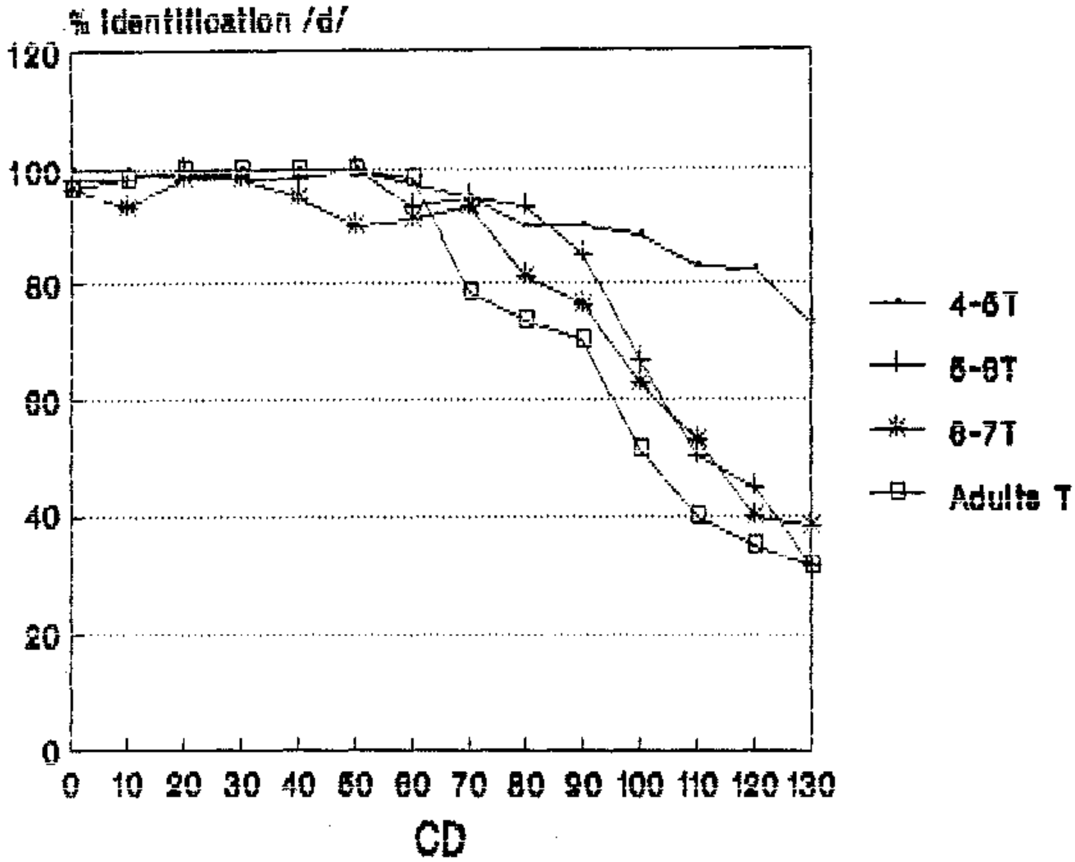


Fig 4.3b: Percent **Identification of / d / for CD**



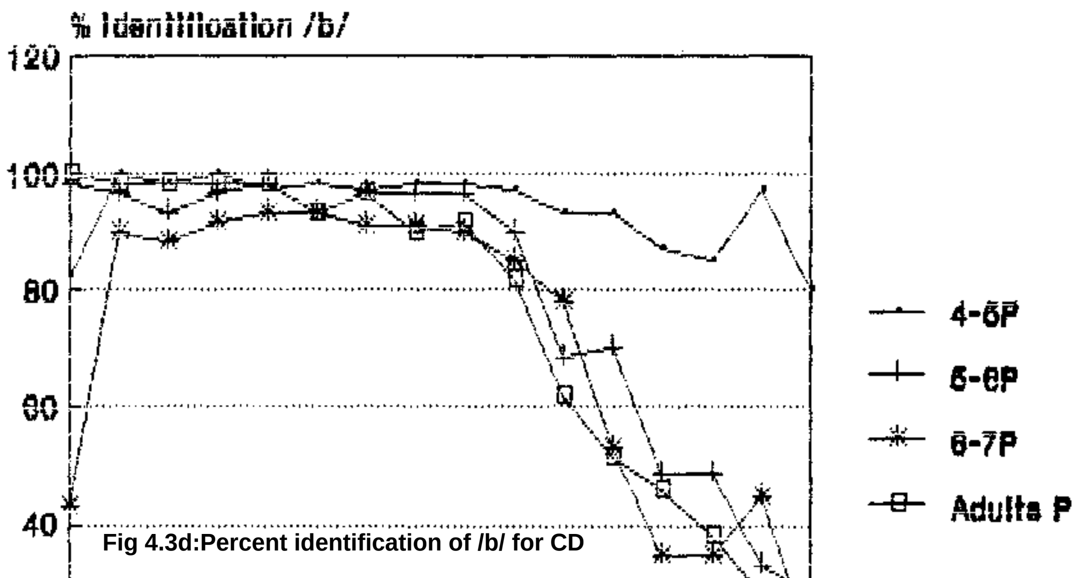


Fig 4.3d:Percent identification of /b/ for CD

It was noticed that there was no change in the percept for /k/ and /t/ in the age group of 4-5 years. The 50% cross over point, lower limit and upper limit were high in the age group of 5-6 years for reasons not known. Figures 4.3 shows the identification functions for various phonemes.

Continuum	4-5	5-6	6-7	Adults
k-g	0	5	5	6
t-d	6	6	6	6
t-d	0	6	5	6
p-b	1	5	6	6

TABLE 4.8: Number of subjects who reached 50 % cross over.

Stimuli	4-5	5-6	6-7	Avg	Adults
aki/agi	-	38.7	28.4	33.6	41.1
ati/adi	23.4	48.2	40.1	37.2	40.8
ata/ada	-	25.2	38.0	31.6	36.3
apa/aba	30.0	38.2	25.5	31.2	32.3

Table 4.9: Mean of 50% cross over points (in m.secs) for closure duration (CD).

The upper limit and the lower limit were high for the retroflex (t-d) while the boundary width varied widely among the children in the age group of 4-5 and 5-6 years. In the ago group of 6-7 years, it was almost a constant

–..Stimuli	4 5	5 0	67	Avg	Adults
aki/agi	-	22.5	14.2	18.4	37.1
ati/adi	8.6	48.0	27.5	28.0	30.3
ata/ada	-	16.0	21.5	18.8	26.3
apa/aba	5.0	26.7	3.0	14.9	19.5

Table 4.10: Lower limit (in m.secs) for closure duration.

Stimuli	4-5	5-6	6-7	Avg	Adults
aki/agi	-	61.0	39.6	50.3	51.8
ati/adi	36.6	64.0	52.6	51.1	48.2
ata/ada	-	38.0	43.0	40.5	43.3
apa/aba	48.0	46.7	37.3	44.0	45.7

Table 4.11: Upper limit (in m.secs) for closure duration.

No linear developmental trend was noticed for any of the measures. However, when the data of the 4-5 year old children was compared with that of 6-7 year olds, it was observed that the boundary width decreased from 4 to 7 years of age. Individual variations were found among children within each age group on the basis of which subjects could be classified as good listeners and bad listeners.

1 Stimuli	4-5	5-6	6-7	Avg	Adults
aki/agi	-	43.5	25.2	34.4	14.8
ati/adi	28.0	18.0	25.1	23.7	17.8
ata/ada	-	22.0	27.5	24.8	17.0
apa/aba	43.0	20.0	24.3	29.1	16.4

Table 4.12: Boundary width (in m.secs) for closure duration.

In the age group of 4-5 years only one subject responded well which was depicted by a smooth identification curve and the remaining five subjects had a fuzzy identification curve. In the age group of 5-6 years, four subjects responded well and the remaining two subjects had multiple cross over points. In the age group of 6-7 years five subjects responded well with a smooth identification curve and one subject had multiple cross over points which might be due to lack of attention.

DISCUSSION

The results indicate that CD were longer for the voiceless than for the voiced with a ratio of 1.59:1. It is a known fact that the closure duration will be longer in voiceless stop consonant. The high articulatory resistance in case of voiceless stop consonants tends to increase the duration of closure. However, the findings that the duration of closure increased from velar place of articulation to bilabial place of articulation was not true for Kannada language. This is in contrast with the results of the study by Fischer- Jorgensen (1979), Repp (1984). No linear developmental trend was observed for closure duration. However, when the CD of 3-4 year old children was compared with that of 6-7 year old children, it was observed that the CD increased from 4 years to 7 years. As children grow, their vocal tract grows allowing more space for air to be accommodated. This physiological maturation reflects itself in acoustically longer closure durat ion.

The category separation score 'S' was high for stop consonants in all the places indicating that the children as early as 3 years use closure duration to differentiate voiced stops from voiceless stops. The category separation scores of children were high for all places of stop consonants when compared with that of adults. This perhaps indicates that children in their production may mainly use CD to differentially produce voiced and voiceless stop« consonants while adults may use other parameters also.

The results of the speech perception experiment indicate that closure duration operates as a cue for voicing of stop consonants. While shorter closure durations cue voiced percept, longer closure durations cue voirolonn percept. This finding is in consonance with the results of the studies done on adults by Lisker (1967), Port

(1980), Price & Simon (1984), CazaIs & Palis (1991), Usha Rani (1989), Vinay Rakesh (1990) and in children by Wolf (1973), Simon (1974) and Zlatin & Koenigsnecht (1976).

While a definite shift in the percept from voiceless to voiced stop was observed in chiIdren in the age group of 5-6 and 6-7 years the same was observed only for retroflex and bilabial in 4-5 year old children. This indicates that children in the age range of 4-5 years are not yet able to distinguish voicing on the basis of closure duration for some places of articulation.

Though there was no linear developmental trend observed, it appears that the boundary width decrease from 4-7 years of age. This agrees with the results of Zlatin & Koenigsnetch (1976) indicating that children become more specific in the perception of voicing.

On comparing the data of the children with that of the adults, it was found that while the change in the percept from voiceless to voiced occurred at a shorter closure duration in children, it occurred at a longer closure duration in adults. Also, the boundary width is wide in children when compared to adults. The later 50% cross over in adults indicate that the voiced and the voiceless stop consonants are well separated. The wide boundary width in children indicates that at intermediate closure durations, the children neither perceive voiced nor voiceless stop and are likely to be confused, and adults seem to have attained better perceptual abilities in differentiating voiced stop from voiceless stop. It appears that oven at the age of 7 years, children have not reached adult standards for speech perception.

On comparing the speech production and speech perception data, it was observed that the S-Ratio and Boundary width reduced from the age of 4 years to 7 years of age. In the earlier age group of 4-5 years, S-Ratio was high for the retroflex and children could identify the percept as voiced when there was a reduction in the closure duration of the voiceless stop consonant. This suggests a relationship between speech production and speech perception. Table 4.13 & 4.14 shows the 50% cross over, range, S-Ratio and Boundary width. The results indicate an increase in the 50% cross over and a reduction in the boundary width in adults. Also, a comparison of S-Ratio and PBW indicates a decrease in both 4 to 7 yrs of age.

	Children	Adults
50% cross over		
k-g	28.4	41 .05
t-d	40.1	40.3
t-d	38.0	36.3
p-b	25.5	32.3
Boundary width		
k-g	25.2	14.75
t-d	25.1	17.8
t-d	27.5	17.0
p-b	24.3	16.41

Table 4.13: 50% cross over & Boundary width in children and adults.

	4-5 years		5-6 years		6-7 years	
	S.Ratio	Boundary width	S.Ratio	Boundary width	S.Ratio	Boundary width
k-g	73	-	67	43.5	23.1	25.2
t-d	112	28	72	18	67.7	25.1
t-d	58	-	50	22	45.2	27.3
p-b	57	43	39	20	54.7	24.3

Table 4.14: S-Ratio and Boundary Width

The data indicates a developmental trend in speech production and speech perception abilities which can be attributed to the physiological maturation of the systems concerned with the mechanism of speech production and speech perception. Though children in the age range of 4-5 years show voicing contrast, it is not complete and even at the age of 7 years they do not show adult approximations.

CHAPTER V

VOICING CUES TO FINAL STOPS

EXPERIMENT IV: PRECEDING VOWEL DURATION (PVD) AS A CUE TO FINAL CONSONANT VOICING

PVD IN SPEECH PRODUCTION:

Among the speech sounds, stop consonants are studied extensively and one of the cues for voicing in stop consonants is preceding vowel duration (henceforth PVD). Typically vowels are longer before voiced than before voiceless consonants (House and Fairbanks, 1953; Peterson and Lehiste, 1960; House, 1961).

Lehiste (1970) and Raphael (1972) investigated PVD in English and reported that it acts as a cue for voicing distinction. In contrast, Sujatha (1992) reported no cueing property of the PVD for voicing of stop consonants in Kannada. However, it has been observed in all these studies that vowel durations are longer preceding voiced and shorter preceding voiceless stops.

Lehman and Sharf (1989) reported that vowel duration increased as the age increased preceding voiceless & vowel duration decreased as the age increased preceding voiced and he also reports a clear developmental trend, where children at the age of eight years achieved adult like pattern.

PVD IN SPEECH PERCEPTION:

Vowel duration is a powerful acoustic cue in American English for adults perception of the voicing contrast in word final position. Specifically, the probability of voiced response increases as PVD increases (Denes, 1955; Raphael, 1972). Vowel duration has also been found to play a similar role in the realization of voicing contrast of postvocalic consonants in speech production. Typically vowels are longer before voiced than before voiceless consonants (House and Fairbanks, 1953; Peterson and Lehiste, 1960; House, 1961). Because this duration cue appears to be learned (Zimmerman and Sapon, 1958; House, 1961; Lehiste, 1970) it of interest to examine the use of this cue in children's developing speech perception.

In adults, however, it has been well established by experimental evidence supporting the conclusion that PVD cue the voicing of stop consonants in the post vocalic final position. In a series of synthetic speech studies by Raphael and his colleagues (Raphael, 1972; Raphael, Dorman, Freeman & Tobi, 1975), using pattern playback to synthesize syllables (CVC/C) ending in voiced and unvoiced stop and fricative found that final consonants were heard as voiceless when preceded by vowels of shorter duration and as voiced when preceded by vowels of longer duration.

Further work involving edited natural speech samples (Fruin and Bischoff, 1976; Hogan and Rozyspal, 1980) found no clear cut relation between length of preceding vowel and perception of final consonants - ie. there were no categorical changes, and constraints of intrinsically short vowel /i/ playing a role. Wardrup-Fruin (1982) presented 521 tokens derived from 52 monosyllables to adults. He concluded that syllable duration was a more significant cue to voicing feature than vowel duration. Evidence to support that PVD is not a strong sufficient necessary cue to disambiguate final voicing is also given in studies by RevoiIe et.al (1982), Davis and Van Summers, (1989) & Fisher and Ohde, (1990).

Crowther and Mann (1990) carried out experiments to test the hypothesis given by Chen (1970) that PVD is a universal cue to final consonant voicing in CVC monosyllables. They compared native speakers of Mandarin, Chinese, English and Japanese. Their experiment revealed that native speakers of English showed the strongest implementation and sensitivity to vocalic duration as a cue to consonant voicing. Mandarin, Chinese and Japanese show only a weaker effect. While there may be a universal tendency to lengthen the vocalic portion before voiced stop, the magnitude of contrast seems to be determined by language specific considerations.

There are only a few studies which have examined the developmental nature of PVD. Higgs and Hodson (1978) found that 4 year olds were significantly poorer than adults in their ability to identify four naturally produced minimal pairs contrasting final voiced and voiceless consonants.

In a study by Krause (1982a) on the development of use of durational cue in 3 year olds, 6 year olds and adults, the duration of vowels was varied to construct three stimulus continua (BIP/BIB, POT-POD, BACK-BAG). Significant developmental differences were found in the perceptual judgement of voicing. These were reflected in that, progressively shorter vowel durations could be used to shift a listener's judgement from a voiced to a unvoiced consonant with increasing age and (2) steeper slope values were demonstrated for adults than for children.

Wardrup-Fruin and Peach (1984) found that 3 year olds were most sensitive to duration (vowel duration) and 6 year olds were most sensitive to spectral cues (final consonant transition) but adults were able to use both duration and spectral cues in making judgements of final consonant voicing.

Lehman and Sharf (1989) studied the development and discrimination in children for the vowel duration cue to final consonant voicing and the perception/production relationships in children for the vowel duration cues to final consonant voicing. Subjects were 30 children divided equally into three age groups and 10 adults. Productions consisted of 15 repetitions of two target syllables (beet/bead) analyzed acoustically for vowel duration. From these were calculated, category boundary, category separation, and variability in production for each subject. Perceptual data were collected using a synthesized speech continuum that varied in vowel duration. Identification responses were used to calculate category boundary, category separation (slope) boundary width and variability (response consistency) for each subject. Mean percentage correct discrimination was derived by using two step and three step two pair same - different paradigms. The results were as follows: (a) category boundary and category separation in production were adult like by 8 years of age (b) variability in production was not adult like by 10 years of age (c) perception categorization (category boundary and category separation) was adult like at 5 years of age (d) perceptual consistency was not adult like until 10 years of age (e) percentage correct discrimination was not adult like by 10 years of age (f) correlations between comparable perception and production measures were nonsignificant and (g) a pairwise comparison analysis indicated that perception was consistently more advanced than production.

In the Indian language context, two studies (Kannada language in adults (Usharani (1989) and Vinay Rakesh (1990) and one in children (Sujatha, 1992) has been done using PVD as a cue to stop consonant voicing. However, in these studies the stops in medial position were considered and the results indicated that PVD does not act as a cue to voicing.

Burham, Earnshaw and Clark (1991) tested English language environment infants, two and six year old children and adults for their identification of sounds of a native (voiced-voiceless bilabial stop) and a non-native (prevoiced-voiced bilabial stop) speech continuum. Categorical perception of the two contrasts diverged with age, increasing for native pontrast and decreasing for the non-native contrasts between two to six years. This difference in developmental course for the perception of native and non-native contrasts indicates an effect of specific linguistic experience on categorical perception.

Thus we find that the literature delineates PVD as a cue to final consonant voicing, although recent findings do question the strength of this cue and attribute language and context effects to play a role in determining PVD as a voicing cue. Indian languages like Kannada and Telugu deserve specific reference. These languages have stops only in the initial and medial position and not in the final position. However, Kannada language has borrowed several English words with final stops which are used commonly by native Kannada speakers. It is of interest to investigate the response of Kannada speakers to these voicing contrast in final stops consonants. Far less is known about children and adults use of vowel duration as a cue to voicing of final consonants in speech perception concerning the language (Kannada) in question.

In an attempt to address this problem, the present experiment examined the value of PVD in the perception of postvocalic stop consonant voicing for Kannada speaking children and adults who had established phonological use of voicing contrast in borrowed final stops.

METHODOLOGY:

PART A: SPEECH PRODUCTION

MATERIAL: Six meaningful English words (back,bag, cap, cab, bat, bad) with three voiceless unaspirated stops[/k/(veIar), /t/ (retroflex) and /p/(bi Iabia I)] and their voiced cognates C/g/i/d/i/b/] respectively in the final position formed the materiaI .

SUBJECTS: Six Kannada speaking normal chiIdren each in the age range of /4-5/, /5-6/ and /6-7/ years [3 males and 3 females in each group] and six adults in the age range of 20-30 years [3 males and 3 females] were selected for the present study. All the subjects had normal speech and hearing.

METHOD: The subjects were instructed to repeat the word after the experimenter into a microphone (AKG D75) which was kept at a distance of 10 cms from the mouth. The list of six words were randomized and iterated five times. The repetition of alI the 30 tokens of each subject were audio- recorded on a Cro2 audio cassette. These audio recordings were digitized at 16000 Hz sampling frequency with a 12 bit A/D converter and using the SSL software developed by VSS . The preceding vowel duration were measured by referring to the waveform and it was measured from the onset of voicing for the vowel to the cessation of the vowel.

ANALYSIS: The data was tabulated and the mean PVD of the five trials for each word was calculated. Also, the range of PVD and the S-Ratio were computed (S-ratio = Mean PVD of voiced stop consonant - mean PVD of voiceless stop consonant).

PART B: SPEECH PERCEPTION

MATERIAL: Three voiced stop consonants in the word final position; wiz;- velar /g/, retroflex /d/ and bilabial /b/ were selected for Experiment-V. Three meaningful picturable monosyllabic borrowed English words in Kannada (bad, bag, cab) were used with these stops in the final position. These words formed a minimal pair with a change from voiced stops to voiceless stops. Table 5.1: Shows the words selected for the study.

Phoneme	Monosyllabic borrowed word	
	Voiced	Voiceless
/g/	bafl	back
/d/	bad	bat
/b/	cab.	cap

Table 5.1: Words selected for Experiment IV.
Phoneme underlined is the phoneme of interest.

A male native Kannada normal speaker aged 23 years served as the subject. The three words with voiced stops in the final position and three words with UNVOICED stops in the final position were acquired as in Experiment-I. The original PVD was measured using the waveform Display of VSS-SSL and spectrogram for each of the stop consonants. The synthetic tokens of PVD were generated using waveform editing procedure in Display of VSS-SSL software. The preceding vowel duration of the word with final voiced stop was truncated (in the steady state) to approximate the average duration of the vowel in the word with voiceless stop (of the respective minimal pair) in steps of two pitch pulses. Burst cue was deleted. Table 5.2: shows the PVD edited stimuli.

Stimuli	/g/	/d/	/b/
Original SO	216.1	249.1	189.1
S1	202.4	238.3	179.5
S2	188	225.4	168
S3	173.6	213.4	157.4
S4	159.3	197.3	148.6
S5	-	-	135.8
Total	50	50	60

Table 5.2: Synthetic stimuli for PVD.

Each word with its synthetic token of truncated PVD was randomized and iterated 10 times forming three tests. The audio-recording was done similar to experiment IV. This served as test material for PVD which consisted of a total of 160 synthetic stimuli. An example of original PVD and truncated PVD is presented in figure-5.1.

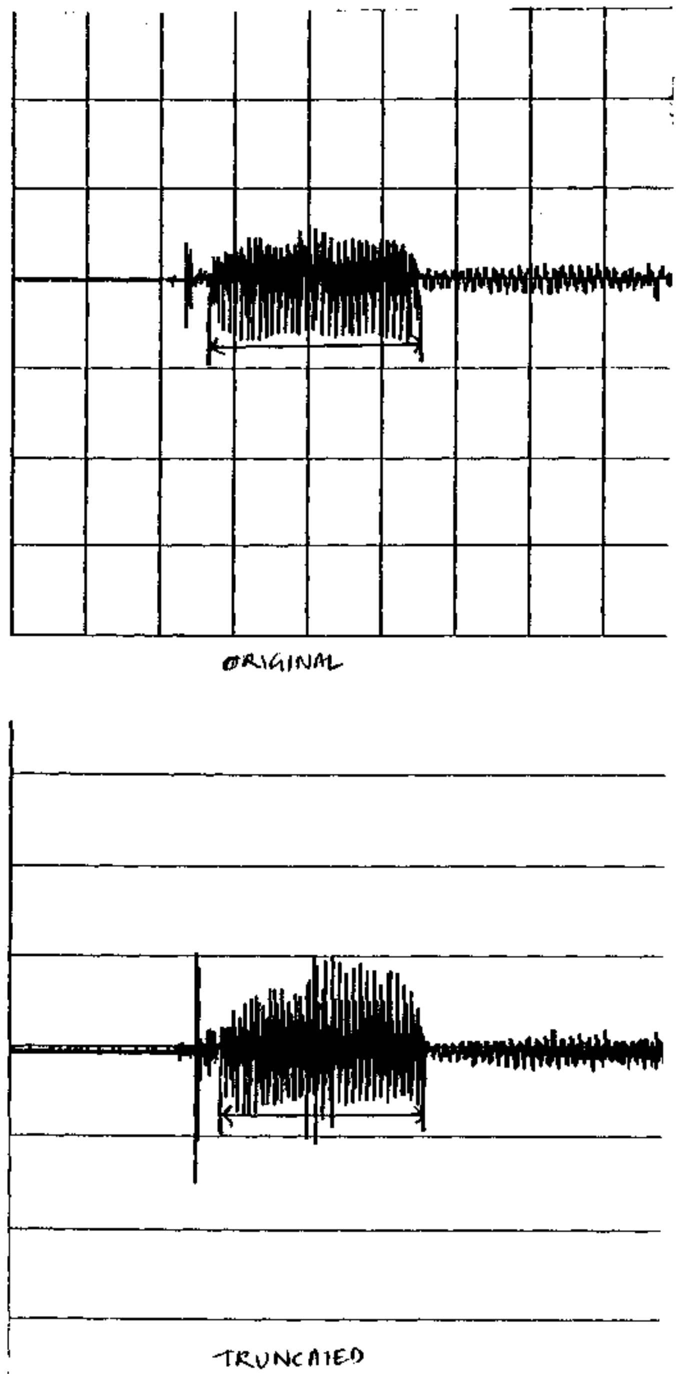


Fig. 5.1: Waveform depicting original & truncated PVD.

The subjects, method and analysis were the same as in experiment III except that in this experiment, the subject had to respond to back/bag, bat/bad and cap/cab.

The responses of perceptual evaluation was analyzed using identification and discrimination curves as described in detail in ChapterjD.50% crossover, LL of PBW, UL of PBW and PBW were calculated.

RESULTS

SPEECH PRODUCTION:

Mean PVD: In general, the mean vowel duration was consistently longer before voiced stops than before the voiceless stops in both children and adults. Among the vowels preceding voiceless stops, those preceding retroflex /t/ was the longest and among the vowels preceding voiced stops, those preceding velar /g/ was longest. No significant differences between the vowel durations preceding voiced and voiceless stops were observed in boys in the age range of 4-5 and 5-6 years. However, girls exhibited significant difference in all the age groups. Table 5.3 shows the mean PVD and Table 5.4 shows the significant difference between the vowel duration preceding voiced and voiceless stops.

Age in Years	k	t	p	Avg	g	d	b	Avg
4-5	194.5	204.8	202.7	200.6	221.2	228.5i	201.5	217.0
5-6	162.8	173.4	175.0	170.4	196.3	200.6	188.5	195.1
6-7	161.6	200.6	189.3	183.8	223.2	210.1	213.3	215.5
Average	172.9	192.9	189.0	184.9	213.5	213.0	201.1	209.2
Adults	179.8	191.5	185.3	185.5	192.4	178.9	195.0	188.7

Table 5.3: Mean preceding vowel duration (msecs).

Age in years	**VL Vs VD**		k Vs g		t Vs d		p Vs b	
	M	**F**	M	F	**M**		**M**	**F**
4-5	**NS**	**S**	**NS**	**S**	**NS**	**S**	**NS**	**NS**
5-6	**NS**	**S**	**NS**	**NS**	**NS**	**NS**	S	NS
6-7	S	S	S	S	S	NS	S	S
Adults	**NS**	**NS**	NS	NS	**NS**	**NS**	NS	NS

Table 5.4: Significant difference between the vowel duration preceding voiced and voiceless stops.
S = Significant NS = Not significant

The vowel duration preceding the stops decreased from 4-7 years though not significantly. When the data was compared with that of adults, it was observed that the average PVD (voiced) was longer in children. Children achieved adult like pattern only for voiceless stops by the age of 7 years.

Range of PVD : The range of vowel duration preceding voiced stops was longer when compared to voiceless stops. The range of PVD linearly decreased from 4 years to 7 years and further in adults. Also, when range of PVD in children was compared with that of adults, adults were found to have lower range than children. Table 5.5 shows the range (highest-lowest) of PVD.

Age in Years	**k**	**t**	**p**	**Avg**	**g**	**d**	**b**	**Avg**
4-5	37.11	68.1	71.2	58.8	73.6	68.1	43.6	61.8
5-6	34.0	41.8	44.0	39.9	50.9	42.5	46.8	46.7
6-7	34.4	41.6	34.1	36.8	54.2	31.8	42.3	42.8
Average	35.2	50.5	49.8	45.2	59.6	47.5	44.2	50.4
Adults	24.01	42.8	29.4	32.1	24.6	32.6	29.7	29.0

Table 5.5: Range of preceding vowel duration (msecs).

Lower limit : There was a significant difference between the lower limit of the vowel duration preceding voiced and the voiceless stops. Vowels preceding retroflex stops exhibited longer lower limits and those preceding bilabial exhibited shorter lower limits. No linear developmental trend was observed across the age groups. However, the lower limits increased from 4 years to 7 years. A comparison of the data of children with adults revealed inconsistent trends. While adults had greater lower limits before voiceless stops, they showed shorter lower limits before voiced stops. T test showed no significant difference between the lower limits of children and adults. Table 5.6 depicts the lower limits.

Age in Years	k	t	p	Avg	g	d	b	Avg
4-5	174.7	172.0	171.0	172.5	184.7	192.5	157.0	178.0
5-6	146.4	153.6	153.2	151 .0	170.3	165.5	169.1	168.3
6-7	179.5	180.0	172.0	177.1	195.6	202.2	190.5	196.1
Average	166.8	168.5	165.4	166.9	183.5	186.7	172.5	180.8
Adults	167.8	171.1	172.3	170.4	181.0	162.9	180.5	174.8

Table 5.6: Lower limits of preceding vowel duration (mseca).

Upper limit : Significant difference between the upper limit of vowels preceding voiceless and voiced stops was observed. When the data was compared with that of adults, it was observed that the upper limit of PVD was shorter in adults. Table 5.7 shows the upper limit for PVD.

Age in years	k	t	p	Avg	g	d	b	Avg
4-5	211.7	240.1	242.7	231.5	253.5	260.5	200.6	238.2
5-6	180.4	195.4	197.2	191.0	221.1	208.1	215.9	215.0
6-7	213.8	221.6	206.2	213.7	250.0	234.0	232.8	238.9
Average	201.9	219.0	215.3	212.0	241.5	234.2	216.4	230.6
Adults	191.8	214.2	201.6	202.5	205.6	295.5	210.1	203.7

Table 5.7: Upper limits of preceding vowel duration (msecs).

S-ratio : The s-ratio was high indicating that the PVD may be used to distinguish voicing. The s-ratio is depicted in Table 5.8. S-ratio was high for /k/,/g/ followed by /t/,/d/ and

/p/,/b/. Also,the s-ratio decreased in adults.

Age	k/g	t/d	p/b
4-5	26.6	16.5	9.2
5-6	25.3	22.1	7.3
8-7	26.0	16.4	22.8
Average	26.0	18.3	13.0
Adults	12.5	9.3	9.6

Table 5.8: S-Ratio for PVD.

SPEECH PERCEPTION:

50% Cross over : Not all children and adults shifted their percept from voiced to voiceless and only those values in which cross over WERE present are considered.In general it was noticed that there was no linear trend in the 50% cross over of PVD across the age groups. Among the places of articulation, retroflex exhibited longer 50% cross over and bilabial the shortest in children while in adults bilabial exhibited longer 50 % cross over and the retroflex the shortest. When the data of children and adults were compared, it was found that 50% cross over in children were longer than that of adults (Table 5.10). However, this was Hot significant statistically (Mann Whitney at 0.05 level).

Continuum	4-5	5-6	6-7	Adults
k-g	5	2	5	5
t-d	0	1	4	1
p-b	0	2	5	1

TABLE 5.9: Number of subjects who reached 50 % cross over.

Stimuli	4-5	5-6	6-7	Avg	Adults
back/bag	187.1	182.9	186.9	185.6	183.9
bat/bad	-	205.4	213.9	209.7	179.2
cap/cab	-	167.6	162.2	**164.9**	210.2

Table 5.10: Mean of 50% cross over points (in m.secs) for preceding vowel duration (PVD).

Lower limit, upper limit & boundary width : No specific trend was observed in the lower limit, upper limit and boundary width in children. On comparing the data of children with adults it was noticed that the lower limit, upper limit and the boundary width was longer for adults than for children (Table 5.11, 5.12 & 5.13).

Stimuli	4-5	5-6	6-7	Avg	Adults
back/bag	165.8	-	173.9	169.9	183.1
bat/bad	-	-	210.4	210.4	180.7
cap/cab	-	186.7	176.8	181.8	186.7

Tab Ie 5.11: Lower limit of phoneme boundary (in m.sees) for preceding vowel duration (PVD).

Stimuli	4-5	5-6	6-7	Avg	Adults
back/bag	192.3	166.5	185.6	181.6	243.0
bat/bad		-	225.3	225.3	239.7
cap/cab		155.0	179.9	165.9	246.4

Table 5.12: Upper limit of the phoneme boundary for preceding vowel duration (PVD).

Continuum	4-5	5-6	6-7	Avg	Adults
k-g	26.5	-	11.7	11.6	59.9
t-d	-	—	14.9	14.9	59.0
p-b	-	31.7	3.1	15.9	59.7

Table 5.13: Phoneme Boundary width for children and adults for preceding vowel duration (PVD).

		Children	Adults
k-g	S-R B.W.	26.0 11.6	12.5 59.9
t-d	S-R B.W.	18.3 14.9	9.3 59.0
p-b	S-R B.W.	13.0 15.9	9.6 59.7

Table 5.14: S-Ratio & boundary width in children and adults (in m.secs) preceding vowel duration (PVD).

EXPERIMENT-V: VOICING DURATION (VD) AS A CUE TO FINAL STOP VOICING.

VD IN SPEECH PERCEPTION:

Voicing duration (in msecs.) was defined as the time between the onset and offset of regular waveform during the closure duration. Those cues in English often granted the mantle of primacy for final stop voicing are preceding vowel duration (Raphael, 1972; O'Kane, 1978) termination rate of the preceding vowel (Parker, 1974) and presence or absence of voicing during consonant closure (Noll, 1960; Wardrup Fruin, 1980). Some of the possible acoustic cues mentioned by Malecot (1970) for final stop voicing are the durations of the final formant transitions, voice bar duration and duration of the silent interval between the voice bar and consonant release.

Greenlee (1978) studied 3-6 year old children using computer editing technique to remove voicing from a CVC final stop (bag : bird). Then vocalic pitch periods were removed successively to achieve four vowel durations. Six tokens of birt and back were altered by repeating pitch periods to achieve four longer vowel durations. The results indicated that younger children failed to perform beyond chance level.

Final stop voicing contrasts are cued primarily by acoustic information in the vicinity of articulatory closure. For e.g. Wolf (1978) made editing cuts at several locations from naturally produced syllables such as /xb/, /xd/ and /xg/. Removal of the entire closure interval produced 16% voiceless responses, while removal of the closure interval and three pitch periods from the vowel to consonant (VC) transition produced 70% voiceless responses. Revoile et.al (1982) reports of similar findings as that of Wolf (1978) on normal hearing & hearing impaired subjects.

Hogan and Rozypal (1980) evaluated the role of PVD for natural speech, which may also contain secondary cues for maintaining this distinction. The stimuli, spoken by a female speaker were 24 English monosyllabic words ending with voiced stops, fricatives and consonant clusters after intrinsically long and intrinsically short vowels. Duration of the vowel nucleus was systematically reduced using a digital gating technique. Recognition rates as a function of vowel duration were also obtained. Category changes take place mainly for intrinsically long vowels and for high vowels in combination with final fricatives alone or in consonant clusters. In other cases, category change cannot be established even after the vowel duration is reduced to only 30% of its original duration. In particular, the presence of a long voice bar for a final voiced stop will make shortening of the vowel perceptually less effective. A multiple regression analysis of the experimental data revea1s that in natural speech not only vowel duration, but also voice bar duration, duration of silent closure preceding tho final release transient,and duration of the release burst/frication noise, depending on the consonant type, vary in weight as cues for voicing under different vowel and consonant type conditions. It was also concluded since all four major factors - vowel duration, voice bar duration, silent closure duration and burst/frication duration are temporal in nature, it seems likely that there may be a minimum threshold duration for each of these segments for the maintenance of the final voiced category over its voiceless counterpart.

Raphael (1981) studied voicing duration from naturally produced tokens of word peg/peck from two different contexts (consonantal and vowel). Voicing duration was then edited in two ways. In version 1 the entire closure period of the /g/ in both tokens of peg was deleted and replaced with an equal duration of silence. In version 2 the closure periods of the /k/ /from typical tokens of peck replaced the /g/ closure of the original tokens of peg/. The duration of /k/ closure were shortened by 21 msec. (peck/v) and 15 msec. (peck/c) so that they were identical with those of the /g/ closures they replaced. The absence of closure voicing was on average, a strong cue for /k/. Also, listeners were sensitive to closure voicing 2. Closure voicing overall emerged as a sufficient cue in isolated stimuli. Raphael also tested other cues like PVD, transition substitution etc. in this study, but closure voicing was a more consistently effective cue than others tested in these experiments.

Ingrisani, Smith and Flege (1984) used a computer editing technique to remove varying amounts of voicing from the syllable final closure intervals of naturally produced tokens of /pEb, pEd, pEg, pag, pig, pug/. Vowels for all six syllables were approximately the same duration, and the final release burst were retained. Identification results showed that VL responses tended to occur if relatively large number (VC) transition had been removed. A second experiment demonstrated that removal of final release bursts had very little effect on the identification. They were, however, unable to find a single acoustic measure, or any combination of measures, that clearly explained listener's voiced-unvoiced decisions.

The literature is *very* scarce on voicing duration to final stops and also in children no study has addressed this acoustic cue in detail. In this context this experiment was conducted. The aim of the experiment was to evaluate voicing duration as a cue to final stop voicing in adults and the developmental nature of this acoustic cue in 4-7 year old Kannada speaking normal children.

METHODOLOGY:

MATERIAL:

The recorded words borrowed from English;- ba:g, ba:d, ca:b (as in Experiment-IV) were used for generating synthetic tokens.

The original voicing duration was measured using the waveform editor of VSS-SSL for each of the stop consonants. The synthetic tokens of voicing duration were generated using the waveform editing procedure in Display of VSS-SSL software. The glottal pulses for each of the voiced stop was truncated and concatenated in steps of two pitch pulses to the corresponding word with the cognate unvoiced final stops. The burst cue was deleted. The voicing duration for the UNVOICED final stops was thus enhanced in steps of two pitch periods to approximate the voicing in the corresponding voiced final stop. Table 5.15 gives the duration of voicing.

Stimuli	/k/	/t/	/P/
Original SO	0	0	0
S1	10	12	10
S2	20	24	20
S3	30	-	30
S4	40	-	40
S5	50	—	50
S6	60	—	60
S7	70	—	70
S8	-	-	80
S9	-	-	90
S1O	-	-	100
S11	-	-	110
S12		—	120
Total	80	30	130

Table 5.15: Stimuli with enhanced voicing durations.

Each word with its synthetic tokens were audio-recorded after randomization and iterations forming three tests as given in Experiment 1. This served as the material for vo icing duration wh ich consisted of 240 synthetic stimuli .

An example of the original UNVOICED word and enhanced voicing duration is given in **Figure** 5.2.

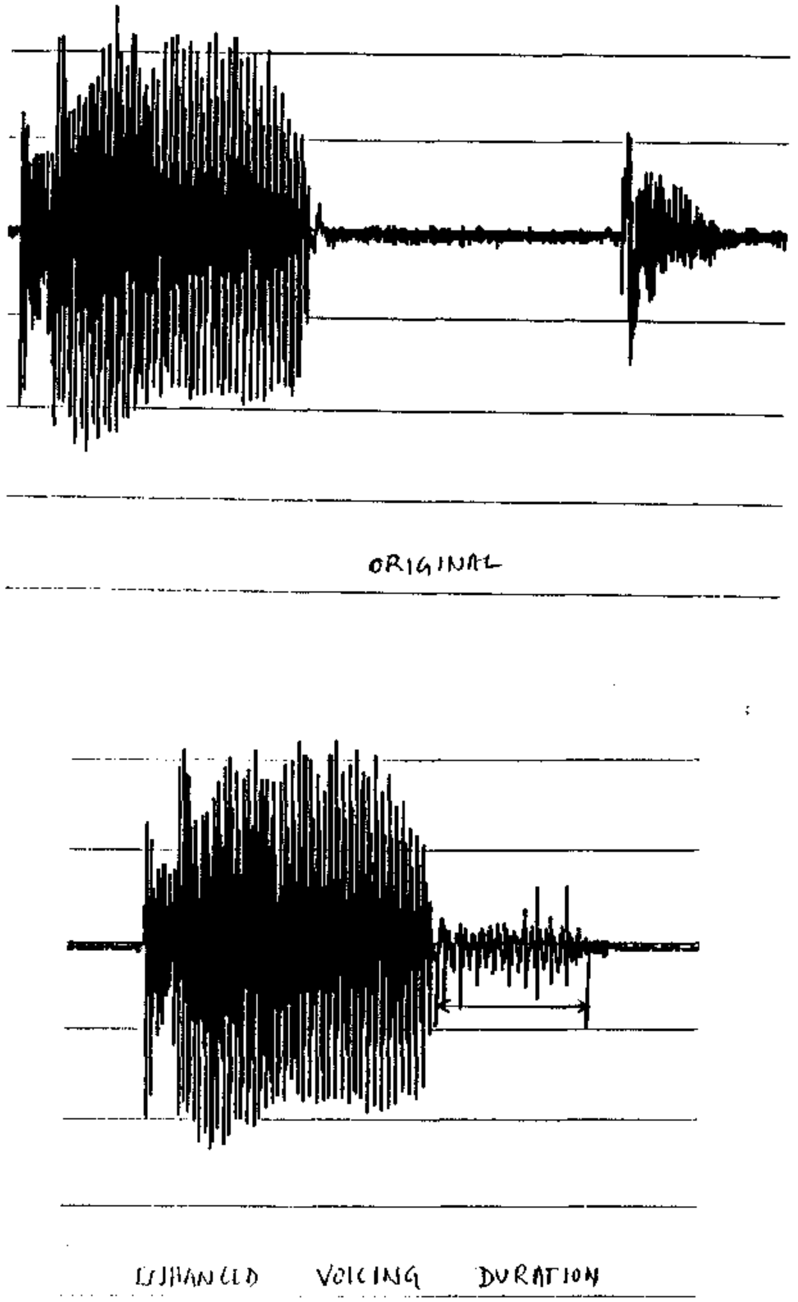


Figure 5.2: waveform **of the original & the enhanced word.**

Subjects and procedure and analysis of responses were done in the same manner as mentioned in Experiment-1.

RESULTS

50% Cross over : In general, it was observed that 50% cross over points increased from the age of 4 years to 7 years. Also, the number of subjects who reached 50% cross over increased as the age progressed, which is depicted in table 5.16. Among the places of articulation, velar exhibited longer 50% cross over and retroflex the shortest both in children and adults. When the data of children and adults were compared, it was found that 50% cross over in chiIdren were longer than that of adults (Table 5.17). Also, children did not shift their percept from voiceless to voiced for all the places of articulation. Statistical analysis (Mann Whitney) revealed a significant difference for retroflex in children and adults (at 0.05 level).

Continuum	4-5	5-6	6-7	Adults
k-g	0	2	3	5
t-d	1	1	3	5
p-b	0	2	0	5

TABLE 5.16: Number of subjects who reached 50 % cross over.

Stimuli	4-5	5-6	6-7	Avg	Adults
back/bag	-	6.8	41.2	24.0	19.4
bat/bad	8.0	8.1	14.3	10.1	5.34
cap/cab	-	16.0		16.0	19.0

Table 5.17: Mean of 50% cross over points (in m.secs) for voicing duration (VD).

Lower limit, upper limit & boundary width : For velar, the lower limit decreased from the age of 5-6 years and the upper limit and boundary width increased (Table 5.18, 5.19 & 5.20). On comparing the data of children with adults it was noticed that the upper limit and the boundary width decreased in adults indicating a fine tuning for perception.

Stimuli	4-5	5-6	6-7	Avg	Adults
back/bag		4.0	2.0	3.0	11.0
bat/bad		-		-	3.2
cap/cab	-	13.0		13.0	12.7

Table 5.18: Lower limit of phoneme boundary (in m.secs) for voicing duration (VD).

Stimui	4-5	5-6	8-7	Avg	Adults
back/bag	-	39.8	43	41.4	39.9
bat/bad	-	-	-	-	13.4
cap/cab		52.0	—	52.0	35.4

Table 5.19: The upper limit of the phoneme boundary for voicing duration (VD).

Continuum	4-5	5-6	6-7	Avg	Adults
k-g	-	35.8	41 .0	38.4	28.9
t-d	-	-	-	-	10.2
p-b	-	39.0	-	39.0	22.7

Table 5.20: The Boundary width for children and adults for voicing duration (VD).

The results indicate that not all subjects shifted their percept from voiceless to voiced stop consonant revealing that VD is not a strong cue for voicing of the final stop consonant in kannada.

DISCUSSION

SPEECH PRODUCTION:

The results revealed several points of interest. First of all, it was observed that vowels preceding voiced stops were longer than those preceding voiceless stops and adults exhibited shorter PVD's compared to children. These results are in consonance with RaphaeI(1971), Lehiste(1970) in English and Sujatha(1992) in Kannada.

Longer vowel durations before voiced stops as reported in the literature are explained on the basis of constant syllable duration. Klatt (1976) comments that the speech system may tend to keep the syllable duration constant and when a vowel precedes a voiced stop (which is shorter than its voiceless counterpart), it becomes longer.

Second, vowel preceding voiced stops showed a linear developmental trend from 4-7 years of age. This is in consonance with the results of Lehman and Sharf (1989) but in contrast with the results of Savithri (1990) and Sujatha (1992).

Third, some developmental trend was noticed in the upper Iimit of PVD. The upper Iimit decreased from 4-7 years of age indicating that the chiIdren learned to finely tune the temporal feature as the age progressed.

Fourth, the ratio of vowel duration preceding voiced and voiceless stops was 1.11:1 and was 1:1.27 for CD. This indicates that the ratio was stronger for CD than for PVD. On comparing the ratio's of PVD and CD it was found that PVD may not be a strong parameter distinguishing voiced and voiceless stops.

Children at the age of 7 years achieve adult like pattern only for vowels preceding voiceless stops but not for voiced stops.

SPEECH PERCEPTION

The results revealed that the voicing duration and preceding vowel duration did not emerge as a cue for voicing in the final position in Kannada. This is in contrast with the study of Crowther & Mann (1990), Hogan and Rozypal (1980), Lehman & Sharf (1989), Raphael (1972), Raphael etal

(1975), Raphael and Wolf (1978), Raphael (1981) and Revoile etal (1982) who had classified voicing duration and preceding vowel duration as a generally sufficient cue for final stop voicing. The PVD results are in agreement with those of WardrUp~Fruin (1982 a) who showed that vowels preceding final voiced stops could be reduced in duration by one-third without eliciting voiceless responses.

The duration of lower limits in children for VD was less than a pitch pulse and it was at least equal to or greater than one pitch pulse in adults. This indicates that while children may not use voicing duration as a cue, adults may. Also, the longer 50% cross over in velar indicates that longer voicing duration are required for the perception of a voiced velar compared to a voiced retroflex. This correlates with the speech production data in that, in Kannada retroflex are the shortest of all the phonemes and even when editing when the duration of a phoneme is reduced, at short durations, it is heard as a retroflex.

Further, the boundary width for VD decreased from children to adults indicating a fine tuning of perception in adults.

No consistent developmental trend in PVD cueing voicing was noticed. These results are not in consonance with the findings of Krause (1982 a) and Lehman and Sharf (1989) who reported a clear developmental trend.

However, it appears that voicing duration and preceding vowel duration may not be used as cue for voicing in final stop consonants (borrowed words) in Kannada language. While an English speaker is tuned to the occurrence of final stops in his language, a Kannada speaker is not tuned as final stop consonants do not occur in their language. Even for a borrowed word with final stop consonant, a Kannada speaker is likely to utter it with a vowel addition. Under these circumstances he is more tuned for the other cues than the PVD or voicing duration which is a must for an English speaker. Considering this, even in the absence of following vowel and the burst release of the stop consonant, the native Kannada speaker may not consider voicing duration and preceding vowel duration as a cue for voicing.

CHAPTER VI

MULTIPLE ACOUSTIC CUES TO STOP VOICING

The acoustic features that bear information on the identity of phonetic segments are commonly called "cues" to speech perception. These cues do not typically have one to one relationships with phonetic distinctions. Indeed, research, usually shows more than one cue to be pertinent to a distinction, all though all such cues may not be equally important. Thus, if two cues, x and y are relevant for a distinction, it may turn out that for any value x, a variation of y will effect a significant shift in listener's phonetic judgments, but there will be some values for which varying x will have negligible effect on phonetic judgements. We say then y is the more powerful cue.

The perception of most, if not all, phonetic distinctions is sensitive to multiple acoustic cues. That is, there are several distinct aspects of the acoustic speech signal that enable listeners to distinguish between, for example, a voiced and a voiceless stop consonant, or between a fricative and an affricate. Although some cues are more important than others for a given distinction, listeners can usually be shown to be sensitive to even the less important cues when the primary cues are removed or set at ambiguous values. All cues that are relevant to a given phonetic contrast seem to carry information for listeners.

Whenever several distinct acoustic cues provide listeners with functionally equivalent information about a single phonetic category contrast, then perceptual "trading relations" can be demonstrated. That is, strengthening the value of one cue can offset or weaken another in listener's perception of the specified phonetic contrast. The relevance of a cue can be predicted from comparisons of typical utterances exemplifying the phonetic contrast of interest. Any acoustic property that systematically co-varies with a phonetic distinction may be considered a relevant cue for that distinction and may be expected to have a perceptual effect when the conditions are appropriate.

In many recent speech perception experiments several acoustic cue dimensions have been varied simultaneously provided the cues are adjusted so that each has an opportunity to influence the perception of the relevant phonetic distinction, it can easily be demonstrated that a little more of one cue can be traded against a little less of another cue, without changing the phonetic percept. This is called a phonetic trading relation.

Phonetic trading relations are a ubiquitous phenomenon whenever two acoustic cues contribute to the same phonetic distinction, they can also be traded against each other, within a certain range. Thus, these trading relations are a manifestation of a more general perceptual principle of cue integration. In phonetic perception, the information conveyed by a variety of acoustic cues is integrated and combined to a unitary perceptual experience.

When the two acoustic parameters cue the same feature le. of voicing, place or manner then the two cues are said to be in co-operating condition. Whi le on the other hand, one of the parameter cues one feature say voicing and another cues place^the cues are conflicting.

In the developmental literature on speech perception, there are several reports that children differ from adults in their responses to variations in single acoustic cues for phonetic contrast.

While these differences between children's and adults' phonetic perception, as based on single acoustic cues, are interesting, evidence is accumulating in the adult speech perception literature, that multiple acoustic cues often interact to specify a single phonetic contrast.

It is known from many previous studies that virtually every phonetic contrast is cued by several distinct acoustic properties of the speech signal. It follows that, within limits set by the relative perceptual weights and by the ranges of effectiveness of these cues, a change in the setting of one cue (which, by itself would have led to a change in the phonetic percept) can be offset by an opposed change in the setting of another cue so as to maintain the original phonetic percept. According to Fitch, Halwes, Erickson and Liberman (1980) there is a phonetic equivalence between two cues with each other. Mann and Repp (1980) on the other hand maintain a distinction between phonetic trading and context effects.

The fact that there are multiple cues for most phonetic contrasts has been known for a long time. Extensive explorations at Haskins Lab. (Delattre, Liberman, Cooper, Gerstman, 1952; Harris, Hoffman, Liberman, Delattre and Cooper 1958), showed 2 formants,2nd and 3rd, contribute to place cue for stop. Lisker (1978 b), drawing on observations collected over a number of years, listed no less than 16 distinguishable cue to /b/ - /p/ distinction in intervocalic position.

From these and many other studies, a nearly complete list of cues has been accumulated over the years. However, the data were typically collected by varying one cue at a time, except Hoffman's (1958) study in which three cues to stop place of articulation were varied simultaneously. The stress on totality of cue was laid by Stevens and Blumstein (1978) where shape of total short term spectrum was critical perceptual cue.

Bailey and Summerfield, 1980, have criticized and denied altogether the usefulness of fractioning the speech signal into cues. In adults, most studies on multiple cues have been done using synthetic speech, some obtained information by cross-splicing components of natural utterances or by combining such components with synthetic stimulus portions.

Cues to stop manner of articulation (ie. to presence vs. absence of a stop consonant) following a fricative and preceding a vowel were investigated by Bailey and SummerfieId (1980), Fitch, Halwes, Erickson & Liberman (1980) and Best, Morrongiello and Robson (1981). In each case, the trading relation studied was that between closure duration and formant onset frequencies in the vocalic portion. Summerfield, Bailey, Siton and Dorman (1981) have shown that duration and amplitude contour of the fricative noise preceding the si lent closure also contribute to the stop manner contrast. Gerstman (1957), Repp, Liberman, Ecardt and Pesetsky (1978), Van Hewan (1979), Dorman, Raphael and Liberman (1979) and Dorman, Raphael and Isenberg (1980) studied four way distinction between fricative-affricate and stop manners using several cues.

Explanation of trading relations on phonetic or auditory is still a controversy as revealed by the experiments of Cutting, (1974); Bailey, Summerfield and Dorman, (1977); Fitch et al. (1980); Remez, Rubin, Pisoni and Carrell (1981), Pastore, (1981) and Best et al. (1981). Context effects due to immediate phonetic context eg. vowel following and preceding have been demonstrated by Summerfield (1975), Summerfield and Haggard, (1974, 1977).

Miller et al. (1976) and Pisoni (1977), Pastore et al. (1981), reported a failure to find equivalent effects of two different variables on VOT category < boundaries. An effect of vocalic context on perception of stop place have been investigated by Hasegawa (1976), Bailey et al (1977), Whalen (1981). In a series of experiments by Mann and Repp (1980, 1981a), Repp and Mann (1981a, 1981b) and Repp (1982, 1983, 1983b, 1984), several effects of context on the perception of stop consonants have been discovered nnd also to CD and amplitude cues of stop consonant manner and place.

VOICING CUES:

Many studies have investigated multiple cues to the voiced-voiceless distinction. For stop consonants in initial position, both voice onset time (VOT) and the first formant (F1) transition contribute to the distinction (Stevens and Klatt, 1974; Lisker, Liberman, Erickson, Dechoritz and Mandler, 1977). The critical feature of the F1 transition, which can be traded against VOT, is its onset frequency. If the onset frequency is lowered in a phonetically ambiguous stimulus, the VOT must be increased for a phonetically equivalent percept to obtain (Lisker, 1975; Summerfield et al (1977). Another cue that has been traded for VOT is the amplitude of the aspiration noise preceding the onset of voicing. If the amplitude of the noise is increased, the duration of VOT must be decreased to maintain phonetic equivalence (Repp, 1979). The fundamental frequency (Fo) at the onset of the voiced stimulus port lot) is another- relevant cue (Haggard, Ambler, and Callow, 1970) that presumably can be traded against VOT (Repp, 1976, 1978b; Summerfield and Roberts, 1981, Abramson and Lisker, 1984).

For stop consonants in intervocalic position Lisker (1978b) has catalogued all the different aspects of the acoustic signal that contribute to the voicing distinction. They include the duration and offset characteristics of the preceding vocalic portion, the duration of the closure interval, the amplitude of voicing during closure, and the onset characteristics of the following vocalic portion (Lisker, 1957, 1978 a, 1978 b; Lisker and Price (1979); Price and Lisker, 1979). Trading relations between voicing cues for intervocalic stops have been studied in French (Serniclaes, 1974) and in German (Kohler, 1979).

The voicing distinction for stop consonants in final position has also been intensively studied. Here, the duration of the vocalic portion is important (especially if no release burst is present) as well as its offset characteristics, the properties of the release burst and the duration of the preceding closure. Trading relations among these cues have been investigated by Raphael (1972, 1981); Wolf, (1978); Hogan and Rozyspal, (1980) among others. Voicing in fricatives has been studied by Massaro and Cohen (1976, 1977) who focused on trading relation between fricative noise duration and Fo at the onset of periodicity.

Similar studies were carried out by Denes (1955), Raphael (1972), Derr and Massaro (1980), Soli (1981).

Basing his conclusions on a perceptual experiment using modified tokens from real speech O'Kane (1978) claims that vowel length is more salient than vowel transition as a cue for voicing in a following final stop. Raphael (1972) attributed the value of the falling F1 as a cue to voicing which has a complex relationship with vowel length. What the presence or absence of the transition seems to do is to determine the position of what Raphael calls the critical vowel duration (CVD) along the dimension of vowel Iength.

Raphael (1981) attempted to demonstrate the relative saliency of various durational cues to voicing in word final stops. He compared the relative contributions of vowel length and vowel transition to the perception of voicing. The various parts of the signal ie. vowel, vowel transition, closure and release were identified as accurately as possible. Two tokens of /peg/, one from each content, ie. "a peg above" and "a peg shorter" were selected and edited in various ways (vowel shortening, transition substitution, closure voicing 1 and 2, closure duration. Release Burst 1 and 2, vowel shortening/transition substitution, closure duration/closure voicing 1 and 2). Three of the altered stimuli are of interest here:

(1) Vowel shortening (VS): The vowel of each of the two tokens of peg were shortened to approximate the average duration of the vowel in /peck/ taken from the same context ie. if vowel length is an effective cue to voicing in a following stop, then it would be expected that listeners would hear /peck/ rather than /peg/.

(2) Transition substitution (TS): The final transitions of the vowels of peg/v and peg/c were deleted and replaced with those from tokens of the vowels of peck/v and peck/c respectively. Likewise, if vowel transition is an effective cue, this modification shouId result in listeners hearing /peck/ when the transition from peck is substituted for that in /peg/.

(3) Vowel shortening/transition substitution (VS/TS): This procedure combines (1) and (2) above. If both vowel transition and vowel length are effective cues, then combining VS and TS should elicit more peck responses than either procedure alone.

Isolated tokens (ie. removed from context) both unedited and with various modifications were presented to listeners having normal speech and hearing, with the following results:

(1) The unedited peg was so identified 96% of the time
(2) VS was only moderately effective as a cue in stimuli from both context (not sufficient cue to /k/).
(3) The effectiveness of TS as a cue was strikingly dependent

on context. When /g/ was followed by unstressed vowel transition was a weak cue but when /g/ was followed by stressed /s/ transition was a strong cue.

(4) For VS/TS there was, of course, no change for the tokens from the pre-consonantaI content (ie. /peck/ responses remained at nearly 100%). The effects of two cues are additive in tokens of pre-vocalic context where peck responses rose to above 70%.

A reasonable summary of Raphael's findings would seem to be that for this set of stimuli, these subjects use vowel transition more effectively than vowel length as a cue to voicing in a following stop.

Revoile et al. (1982, 1987) studied multiple cues of adjusted vowel duration, transition switched and transition deleted in order to find the relative saliency of different acoustic cues. Vowel length minimally affected voicing perception. Switching VTs resulted in listeners perceiving the voicing characteristics of the following stop to be that of the stop in the syllable in which the VT was produced. Deletion of VT impaired the overall identification of voicing in the following stop.

Thus, in general, phonetic contrasts are cued acoustically by more than one characteristics of the signal. In particular, the post vocalic voicing distinction is signaled not only by vowel duration but also by the presence/absence of voicing during preconsonantal closure (Hogan and Rozypal, 1980) or during release of the final consonant (Malecot, 1958).

A developmental study has been conducted by Greenlee (1978), using multiple cues. She used a computer editing technique to remove the final voicing from /bag/ and /bird/. Then vocalic pitch periods were removed successively to achieve four vowel durations. Voiceless tokens (eg. Birt and back) were altered by repeating pitch periods to achieve four longer vowel durations. These alterations resulted in four step continua. A set of unaltered stimuli were used as controls. None of the altered stimuli contained voicing during the postvocalic closure periods. Subjects were children aged 3 and 6 years and adults. Greenlee found that two of the continua of altered words did not produce two distinct categories. However, for the two successful continua, clear age trends did emerge. The 3 year olds that "not seem to change their responses to any word and the responses for the youngest group tend to hover around the center (or chance area) of the graphs". Between age 6 years and adult, boundaries became steeper and less modification qf the original stimulus was required to produce a change in categorization. Greenlee questioned as to why the youngest children failed to perform beyond a chance level, suggesting that either task difficulty or acoustic characteristics of the stimul i might be responsible. She suggests that for three year olds, vowel duration differences presented in isolation may not be sufficient cues to final voicing contrast. Perhaps the younger children need more acoustic differences in order to make perceptual differentiations. A comparison between performance on the altered stimuli and the unaltered full cue stimuli showed that children were more accurate for voiced stimuli when closure voicing was also present (True for both groups of children). The voiceless stimuli were altered only by increasing the number of pitch periods and there was no difference in accuracy for those stimuli on the part of either 3, or 6 year olds. Since, performance improved for full cue voiced stimuli, Greelee concludes that probably acoustic characteristics, and not task difficulty, influenced performance on the altered stimuli. This was a conclusion to which additional attention was paid by Simon and Fourcin, (1978).

Simon and Fourcin (1978) tested French and British children between ages 2 and 14 years using stimuli that varied in VOT and first formant characteristics. This study is exceptional in that stimuli were generated semi-factorially rather than as a one dimension continuum. That is, for VOT less than 30 msec, the first formant was either level or rising. The rationale for this variable was that, in English, the extent of the F1 transition is greater for voiced than for voiceless stop consonants (Liberman, Delattre and Cooper, 1958) and level F1 influences subjects to prefer a voiceless response (Lisker, 1975; Summerfield and Haggard, 1977). Use of a factorial design allows the investigator to observe the effect of variables that may contribute unequally to the perception of some speech sound contrast.

In this study, each child contributed only three responses for each stimulus item and data are presented in grouped format. The authors provide a characterization of overall response types across age. The pattern that emerged for the British children was the following:

1. Children of 2 and 3 years were most consistent in their responses to stimuli from end points of the continua. The children labeled intermediate items in a random fashion.
2. Children's responses to individual stimulus items became more consistent as age increased and by 4 years responses were categorically divided between the two response possibilities.
3. Children of 2 and 3 years did not respond differentially to the absence of a rise in F1 in stimuli with short VOT. However, in the data from 4,5 and 6 year olds., there is evidence that the children were more reluctant to label as voiced stimuli with steady state F1. Data from 8, 11, 12, 13, 14 year olds exhibit a strong migration of data points for steady state F1 stimuli toward the voiceless response alternative.

French children did not respond at all to the F1 variable which may not be important in their language. They also lagged somewhat behind their English counterparts in achieving categoricalness in labeling. Simon and Fourcin suspect that the sharpness of category boundary increases "with the number of cooperating distinctive acoustic features". This remark is reminiscent of Greenlee's (1978) statement that, "Perhaps the younger children need more acoustic difference in order to make perceptual differentiations".

Robson, Morrongiello, Best and Clifton (1982) extended their investigation to children's speech perception. By using the same stimuli as in Best et al. (1981),ie. using the "say" -"stay" contrast - systematically manipulating two acoustic cues that specify the presence/absence of the alveolar stop following the word initial /s/ and F1 onset frequency and duration of the silent closure. Five year old children were tested for perceptual trading between the same temporal cue (silence duration and a spectral cue F1 onset frequency) for the say stay distinction. Alternately, if children attend primarily to the acoustic properties of the stimuli, one would expect that they would fail to integrate perceptually the temporal and spectral cues as information about a unified phonetic category. In that case, they would hear the auditory difference between differently cued stimuli even within a phonetic category and would thereby discriminate the conflicting cue contrasts as well as they discriminate co-operating cue contrast. Children showed a smaller trading relation that had been found with adults.

They did not differ from adults, however, in their perception of an "ay-day" continuum formed by varying F1 onset frequency only. In adults, the averaging trading relation obtained from listener's identification performance was evident in a "say" - "stay" boundary shift of 24.6 msec. In other words, in order to be perceived as "stay", a stimulus with a high F1 onset frequency (430 Hz) required approximately 25 msec, additional silence between the /s/ and the vocalic portion than did a stimulus token having a low F1 onset frequency (230 Hz). The cues made to "co-operate" or "conflict" phonetically supported the notion of perceptual equivalence of the temporal and spectral cues along a" single phonetic dimension. The results indicate that young children, like adults, perceptually integrate multiple cues to a speech contrast in a phonetically relevant manner, but they may not give the same perceptual weights to the various cues as do aduIts.

Robson et al . proposed that the children may have weighted the transitional information relatively more heavily and the temporal information relatively less heavily than adults do ie. perhaps the children were more sensitive to transitional cues than adults - a possibility encouraged by the finding that any transition even a brief one was sufficient to elicit some "stay" responses from the children. This suggestion provides a possible outcome that children would prove even more sensitive to some kinds of co-articulatory effects than adults.

Krause (1982) conducted an experiment to examine the development of vowel length as a cue to phonological voicing in post vocalic stops among children. She synthesized three monosyllabic spectral configuration to represent the pairs bip/bib, pot/pod, and back/bug. Two pairs of spectra those for pot/pod, and back/bag, contained falling F1 transitions, while the third, that for bip/bib contained a level transition tokens were varied along vowel length. She presented these stimuli to three different age groups 3 year olds, 6 year olds and adults. Her data suggests that as the age of the listener increased, progressively shorter vowel length were required to shift a listener's judgment of a postvocalic stop from voiceless to voiced. In other words, English speakers appear to acquire the use of vowel length as a voicing cue as they mature. Of particular interest, however, are the two groups of children who did not respond according to general pattern. One group labeled all the back/bag stimuli (all of which had a falling F1 transition) as bag. A second group labeled all the bip/bib stimuli (all of which had a level F1 transition) as bip. Krause notes that - "for some chiIdren, the presence of an F1 offset transition may always cue a voiced stop, and absence of an F1 transition may always cue a voiceless stop, independent of vowel duration (Liberman, et al. 1958; Raphael, 1972)".

The above studies in chiIdren provide on evidence that children perform more accurately when they are presented with stimuli that vary along more than one dimension. However, the results of the study by Simon and Fourcin (1978) in French speaking chiIdren suggest that this effect may be language specific. That is, acoustic attributes of the speech signal must occur in the same relations that are criterial in the native language. Cues may differ in value across language and only linguistically relevant cues would be expected to aid in phoneme perception. At the same time, the wtre presence of acoustic redundancy does not guarantee effectiveness, if development is not sufficiently advanced. The additional cues to voicing exemplify the fact that phonemic distinctions depend on numerous acoustic characteristics. Some of these characteristics may correspond with specific auditory sensitivities, whereas other characteristics may require some perceptual computations. Development may be required both for extracting (or learning to attend to) certain acoustic characteristics and for acquiring perceptual algorithms or structures in which these characteristics may enter.

Particularly as studies in multiple cues are vitally lacking in Indian context to see the effect of changes in perception of voicing when two temporal cues are varied, Experiments VI, VII and VIII were planned to systematically study the developmental emerging patterns of perception of multiple acoustic cues to stop consonant voicing in 4-7 year old Kannada speaking normal children. The Experiments VI, VII and VIII aim at determining the effect of multiple cue.

Manipulation in which and their response to it by way of their weighting of the relative or combined strength of acoustic parameters as perceptual cue for voicing in Kannada. Experiment VI deals with closure duration+transition substitution as cues to medial stop voicing, Experiment VII deals with shortening preceding vowel duration+ transition substitution as cue to final stop voicing and Experiment VIM deals with voicing duration+transition substitution as cues to final stop voicing.

METHODOLOGY:

EXPERIMENT-VI: CLOSURE DURATI0N+ TRANSITION SUBSTITUTION - AS A CUE TO VOICING IN MEDIAL STOP CONSONANTS.

MATERIAL:

Four voiceless stop consonants in the medial position (velar /k/, retroflex /t/, dental /t/ and bilabial /p/) were selected for this experiment. Eight meaningful bisyllabic Kannada words /a:ki/, /a:ti/, /a:ta/, /a:pa/ /a:gi/, /a:di/, /a:da/, & /a:ba/ with these stops in the medial position were considered.

An adult native Kannada speaking normal male aged 23 years served as the speaker (subject). The four words with voiced stop in the medial position were written one each on a card & were visually presented with one card at a time and the subject was instructed to utter the word into a microphone (cardiode unidirectional), kept at a distance of 10 cms from the mouth in a sound treated room of the Speech Science Laboratory. These were recorded on a data acquisition system and were then digitized on a computer PC-AT-386 DX with a sampling rate of 16,000 Hz and 12 bit resolution and stored in the computer memory. The digitized waveform was displayed on the screen of the computer using the program DISPLAY on the SSL developed by VSS (Voice and Speech System, Bangalore). The original CD was measured using the waveform Display of VSS-SSL for each of the stop consonants. In the similar fashion, the vowel consonant transition of the vowel preceding the voiceless stop and the voiced stop in the medial position was measured referring to the spectrogram. The synthetic tokens of CD and TD (A multiple cue condition) were generated using the waveform editing procedure in Display of VSS-SSL.

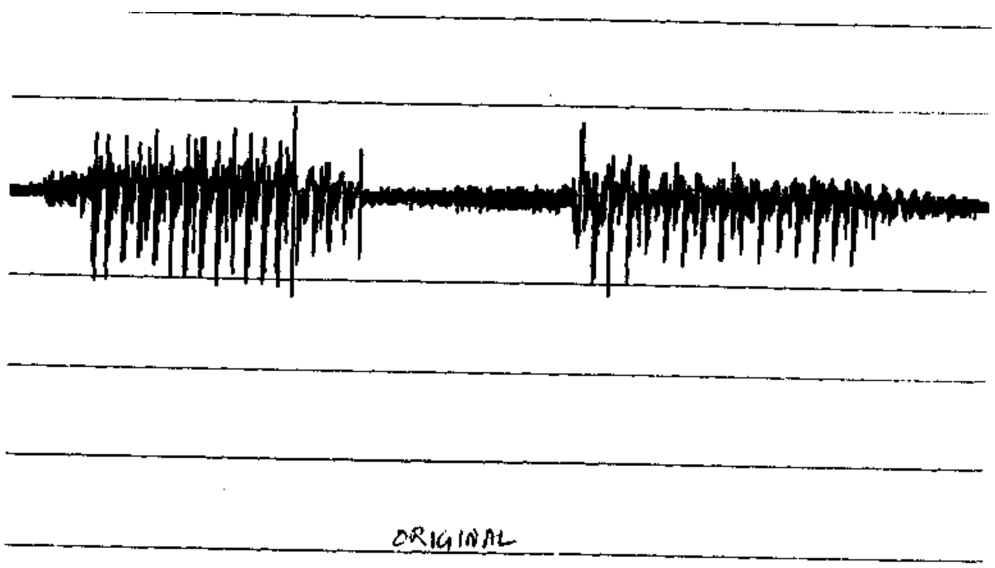
The VC transition (from the waveform) of the vowel in the UNVOICED stop cognate in the medial position measured as described were deleted and replaced with scaled transition from voiced counterparts (measured in the same manner). The steady state portion of the vowel was maintained equal to the original vowel in the voiceless cognate. The CD was then truncated in 10 msec. steps (as in Experiment III). The substituted transition duration are in Table 6.1. In this case it was a "co-operating condition'" le. both the cues altered supported voicing.

Phoneme	Original TD=UV	Duration substituted=V	Total stimuli
/k/	16	24	130
/t/	27	28	130
/j/	17	22	90
/p/	20	21	150

Table 6.1: Substituted transition duration and the total number of stimuli (with 10 iterations).

Each word with its synthetic tokens was considered as a test and within each test, the tokens were randomized and iterated ten times. These synthetic tokens with multiple acoustic cue condition in four places of articulation were then audio-recorded on a metallic cassette with an ITI of 3 Sec and ISI of 5 Sec using the playbat program. This served as the test material for CD + TD condition. An eg. of original stimuli and synthetic stimuli with CD truncated and TD substituted is shown in Figure 6.1.

Subjects, procedure and analysis of identification and discrimination functions were carried out as in Experiment III.



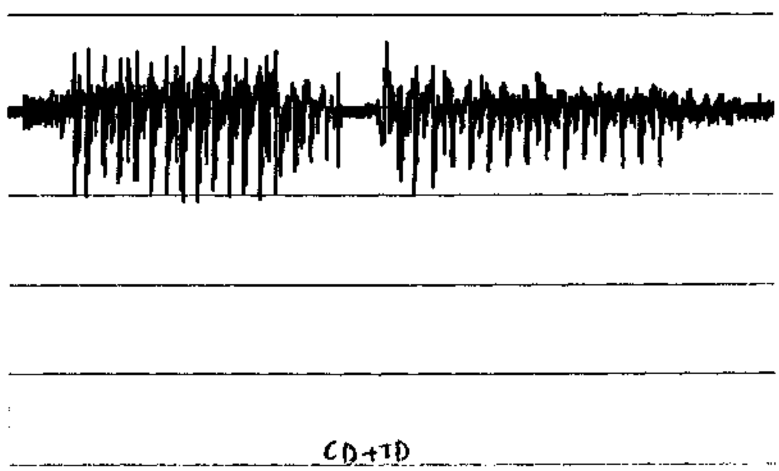


Fig 6.1: Waveform of the **word with** original CD and CD+TD condi t ion.

EXPERIMENT VII: VOICING DURATION+ TRANSITION DURATION AS A CUE TO VOICING OF FINAL STOP CONSONANTS.

MATERIAL: Six meaningful borrowed EngIish words use in Kannada (back/bag, bat/bad, cap/cab) were used. These words were uttered by a 28 year old Kannada speaking normal male subject and were digitized with a computer using a 12 bit ADC at 16 K Hz sampling frequency. The original VD was measured using the waveform Display of VSS-SSL for each of the stop consonants. In the similar fashion, the VC transition (F2) of the vowel in the voiced stop cognate in the final position was measured.

The synthetic tokens of VD and TD (A multiple cue condition) were generated using the waveform editing procedure in Display of VSS-SSL. The VC transition of the vowel in the voiceless stop cognate in the final position measured as described were deleted and replaced with scaled transition from voiced counterparts (measured in the same manner). The burst cue was deleted and the glottal pulses for each of the voiced stop was truncated and concatenated in steps of two pitch pulses to the voiceless final stops. Each word with its synthetic tokens was considered as a test and within each test, the tokens were randomized and iterated ten times. These synthetic tokens with multiple acoustic cue condition in three places of articulation were then audio-recorded on a metal I ic cassette with an ITI of 3 Sec and ISI of 5 Sec using the playbat program. A total of 160 tokens were audio recorded which formed the material. Subjects, procedure and analysis of identification and discrimination functions were carried out as in Experiment III.

EXPERIMENT VIII : PRECEDING VOWEL DURATION+ TRANSITION SUBSTITUTION AS CUE TO VOICING OF FINAL STOP CONSONANT VOICING.

MATERIAL: The material used for this experiment VIM is similar to that of experiment VII. The synthetic tokens of PVD and transition duration were generated using waveform editing procedure in display of VSS-SSL software. The transition of voiced stop was replaced with that of the voiceless. The preceding vowel duration (in the steady state) of the word with final voiced stop was truncated in steps of 10 msec to approximate the average duration of the vowel in the word with voiceless stop. These synthetic tokens with multiple acoustic cue condition in three places of articulation were then audio-recorded on a metallic cassette with an ITI of 3 Sec and ISI of 5 Sec using the playbat program. A total of 160 tokens were audio-recorded which formed the material. Subjects, procedure and analysis of identification and discrimination functions were carried out as in Experiment III.

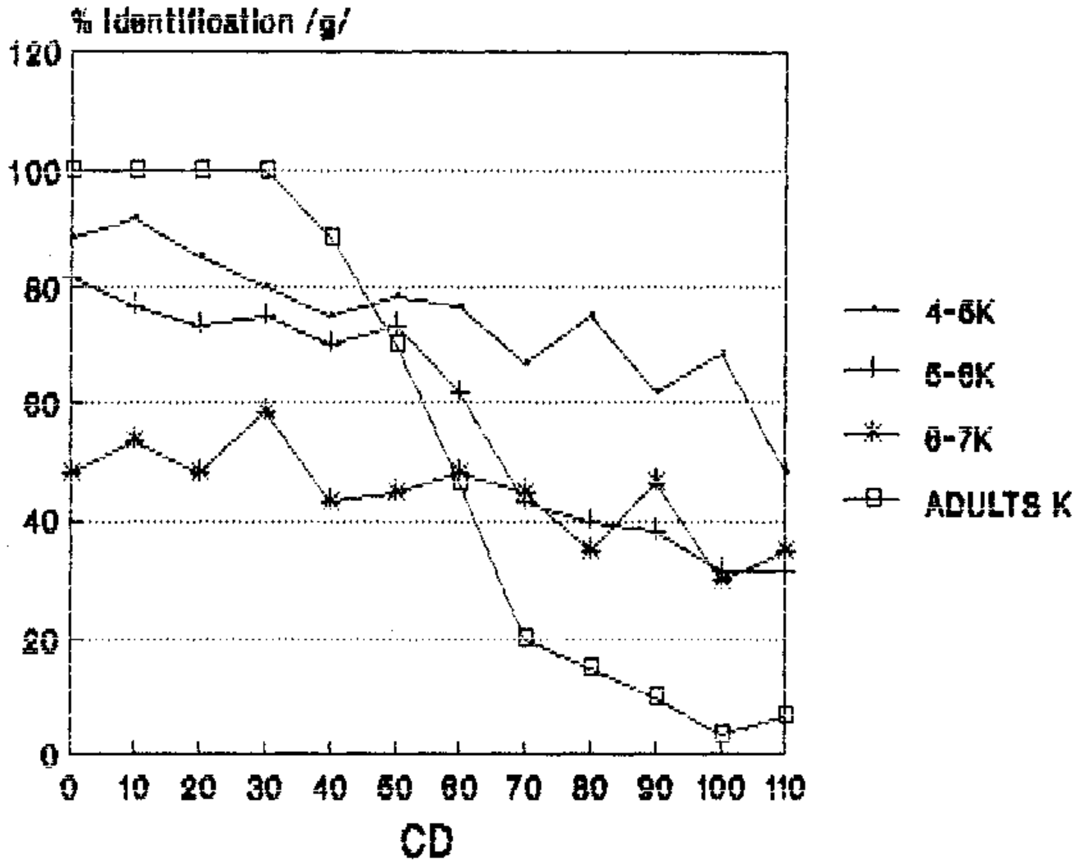
RESULTS

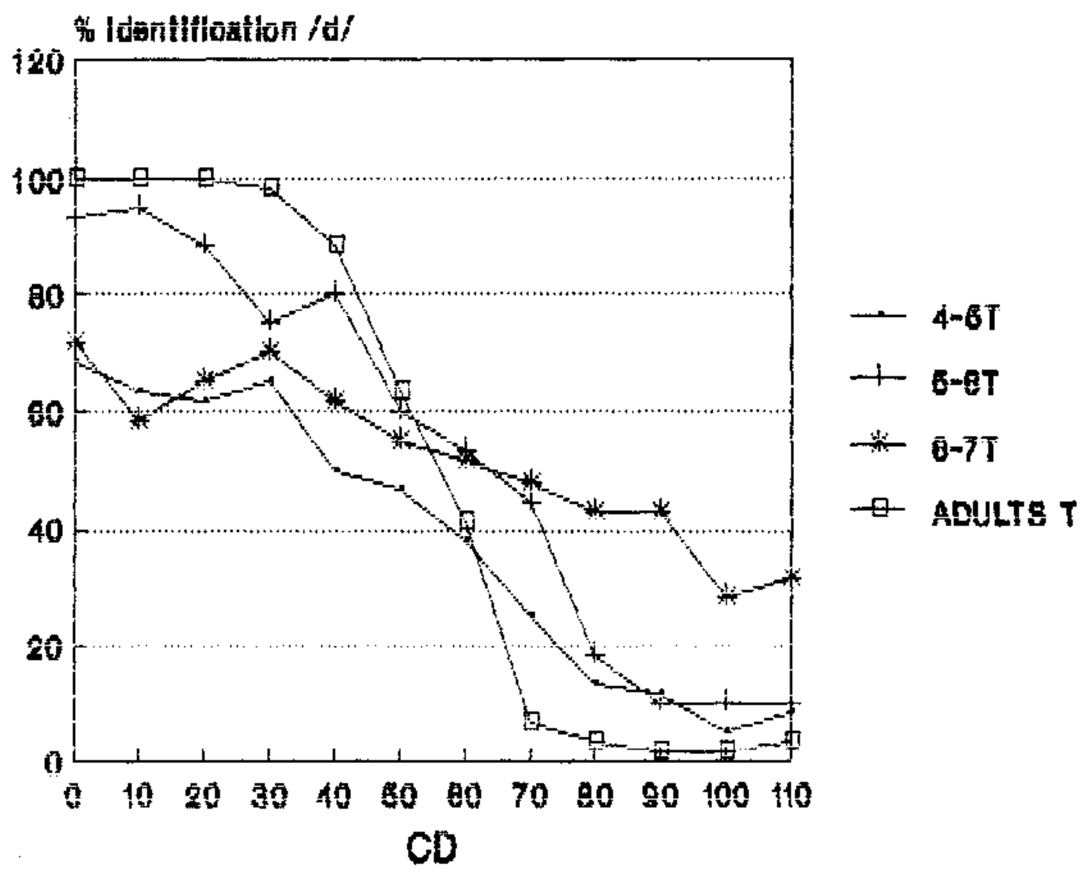
EXPERIMENT V!:

50% CROSS OVER: It was noticed that the 50% cross over point increased from the age of 4 years to 7 years and further in adults for velar and dental showing a clear developmental trend, but this trend was not observed for retroflex and bilabial. Among the places of articulation, retroflex exhibited longer 50% cross over in 4-5, 5-6 years and adults and velar exhibited the shortest. The number of subjects who reached 50 % cross over are depicted in table 6.2. When the data of children and adults were compared, it was found that the 50% cross over in adults were longer than that of children (Table 6.3). Statistical analysis (Mann-Whitney) revealed significant difference for velar in children and adults (0.05 level). When the data of single and multiple cues were compared, the results revealed that the multiple acoustic cues condition exhibited higher 50% cross over values of about 15-20 msec than in the single cue condition which indicates that multiple cue condition enhances the cueing for voicing. Figure 6.2 shows the identification functions for CD+ TD.

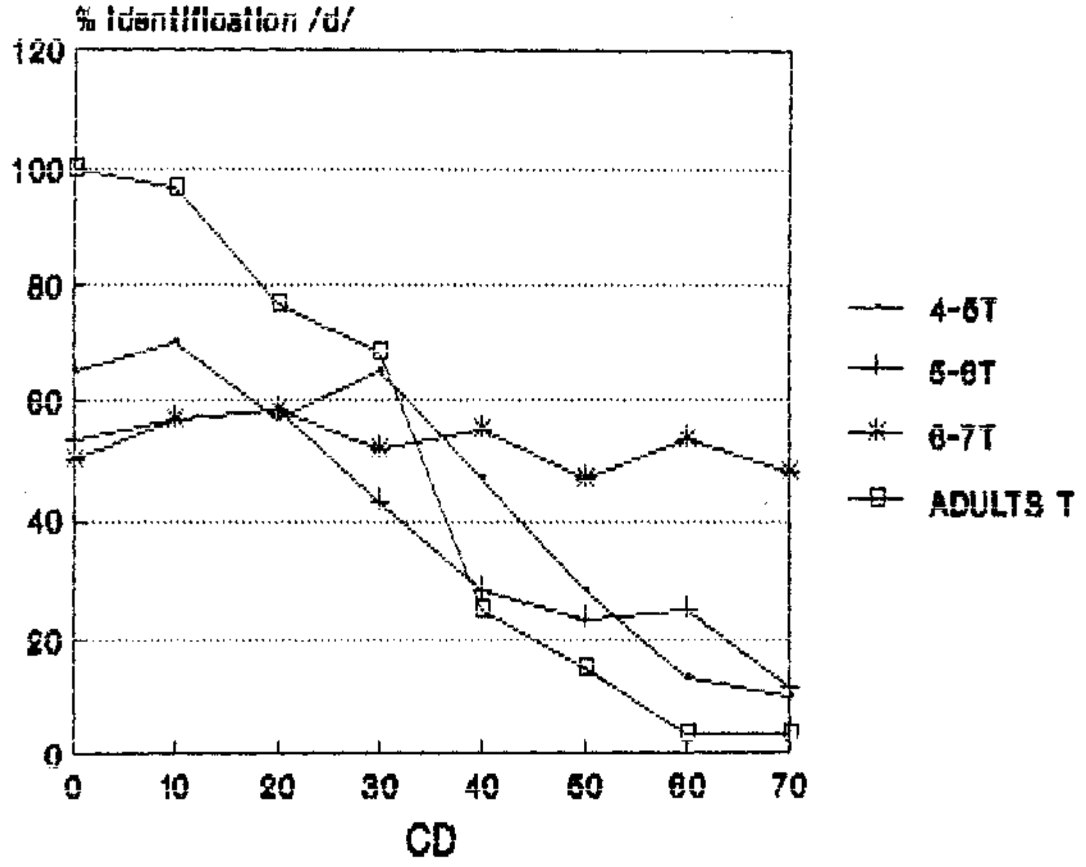
Cont i nuum	4-5	5-6	6-7	Adults
k-g	4	6	2	6
	3	5	3	6
t-d	4	4	5	6
p-b	5	4	4	6

TABLE 6.2: Number of subjects who reached 50 % cross over.





Flo 6.2b: Percent Identification of /d/ for CDTD



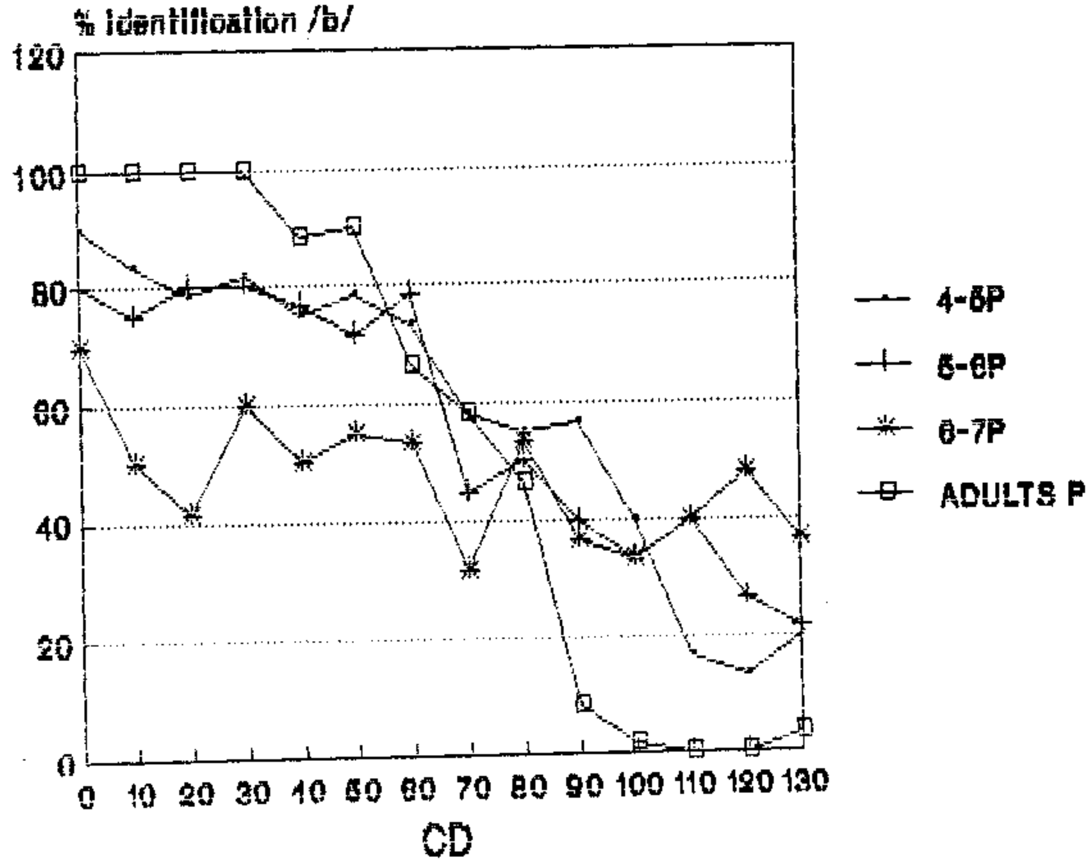


Fig 6.2d: Percent Identification of /b/ for CDTD

Stimu1i	4-5	5-6	6-7	Avg	Adults
aki/agi	26.6	38.3	41 .5	35.5	59.3
ati/adi	64.0	57.7	60.0	60.6	63.5
ata/ada	46.0	54.0	56.8	52.3	56.8
apa/aba	61 .8	55.3	81 .3	66.1	61 .6

Table 6.3: Mean of 50% cross over points (in m.secs) for closure duration & transition duration (CD+TD).

LOWER LIMIT: The results revealed that there was no I inear developmental trend in the lower limit of CD+TD across the age groups. In general, retroflex and dental exhibited a decrease in lower limit and the velar and bilabial exhibited an increase in trend from the age of 4 to 7 years. Among the places of articulation, retroflex exhibited longer lower limit and velar exhibited the shortest in both children and adults. When the data of children and adults were compared, i t was noticed that the lower limit in adu!ts were longer than that of children (Table 6.4). Statistical analysis (Mann-Whitney) revealed a significant difference between the Iower limits of ch ildren and adults at 0.05 level.

Stimuli	4-5	5-6	6-7	Avg	Adults
aki/agi	18.0	28.6	25.0	23.9	48.5
ati/adi	47.7	42.7	32.7	41.0	59.3
ata/ada	37.3	37.8	27.0	34.0	51.7
apa/aba	27.5	31.0	35.8	31.4	53.6

Table 6.4: Lower limit of phoneme boundary for closure duration & transition duration (CD+TD).

UPPER LIMIT: In general, it was observed that there was no linear developmental trend across the age groups. Among the places of articulation, no significant difference was noticed across the age groups. On comparison, the upper limit of children were longer than that of adults (Table 6.5). A significant difference between the upper limit of adults and children for the dental place of articulation was observed (Mann-Whitney test at 0.05 level).

Stimu1i	4-5	5-6	6-7	Avg	Adults
aki/agi	81.3	75.3	89.0	81.9	71.8
ati/adi	76.0	88.2	62.5	75.6	67.9
ata/ada	85.3	67.8	79.7	77.6	61.8
apa/aba	61.2	79.3	119.0	86.5	70.5

Table 6.5: Upper limit of the phoneme boundary for closure duration & transition duration (CD+TD).

BOUNDARY WIDTH: No developmental trend was observed for boundary width in children. Among the various places of articulation, boundary width was longest for velar and shortest for retroflex in both children and adults. On comparison, boundary width was longer for children than that of adults indicating that fine tuning is done in adults (Table 6.6).

Continuum	4-5	5-6	6-7	Avg	Adults
k-g	63.3	46.7	64.0	58.0	23.3
t-d	28.3	45.5	29.8	34.6	8.6
t -d	48.0	30.0	52.7	43.6	9.8
p-b	33.7	48.3	83.2	55.1	16.9

Table 6.6: The Boundary width for children and adults for closure duration & transition duration (CD+TD).

EXPERIMENT VII:

50% CROSS OVER: The results revealed that there was no developmental trend in the 50 % cross over of VD+TD across the age groups. Among the places of articulation, bilabial exhibited longest 50 % cross over in both children and adults. Retroflex in children and velar in adults exhibited the shortest 50 % cross over. When the data of chiIdren and adults were compared, adults had higher number of 50 % cross over (Table 6.7) & also, on comparison children had longer 50 % cross over values than adults as depicted in Table 6.8. Statistical analysis (Mann Whitney) revealed significant difference only for velar when the data of children and adults were compared. When the data of single and multiple cue was compared, the results revealed that multiple acoustic cues condition exhibited higher 50 % cross over values than in single cue condition which, indicates that multiple cue condition enhances the cueing for voicing.

Continuum	4-5	5-6	6-7	Adults
k-g	1	2	2	6
t-d	**0**	**2**	1	**3**
p-b	**1**	**6**	6	**6**

TABLE 6.7: Number of subjects who reached 50 % cross over.

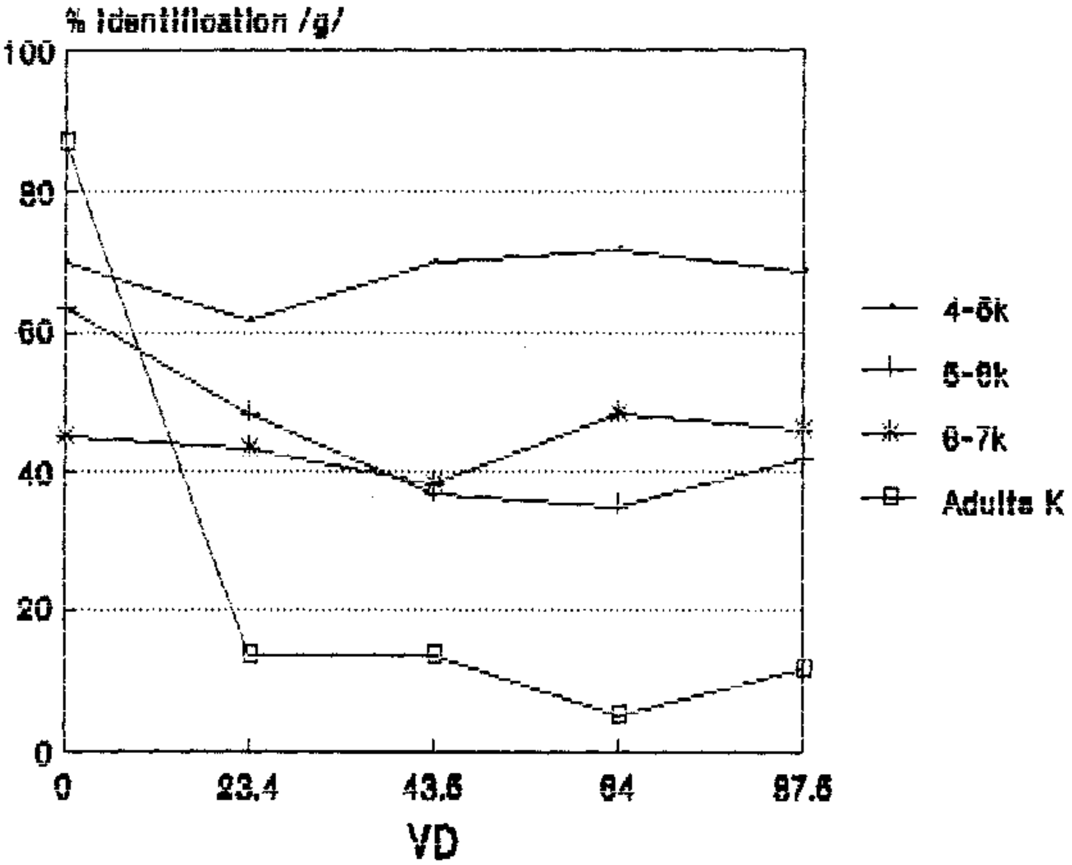
Stimuli	4-5	5-6	6-7	Avg	Adults
back/bag	36.0	47.5	34.6	39.4	10.6
bat/bad	—	15.0	11.3	13.2	12.9
cap/cab	129.0	34.6	27.8	63.8	28.9

Table 6.8: Mean of 50% cross over points (in m.secs) for voicing duration & transition duration (VD+TD).

LOWER LIMIT, UPPER LIMIT & BOUNDARY WIDTH: A developmental trend was observed only for bilabial in all the age groups for lower limit, upper limit & boundary width (Table 6.9, 6.10 & 6.11). A comparison of the data of children and adults revealed longer upper limit and boundary width in children. Statistical analysis (Mann Whitney) revealed no significant difference between children and adults and for single and multiple cues at 0.05 level.

Stimuli	4-5	5-6	6-7	Avg	Adults
back/bag		21.5		21.5	5.2
bat/bad		5.3		5.3	5.7
cap/cab	12.0	13.2	15.8	13.7	18.1

Table 6.9: Lower limit of phoneme boundary (in m.secs) for voicing duration & transition duration (VD'TD).



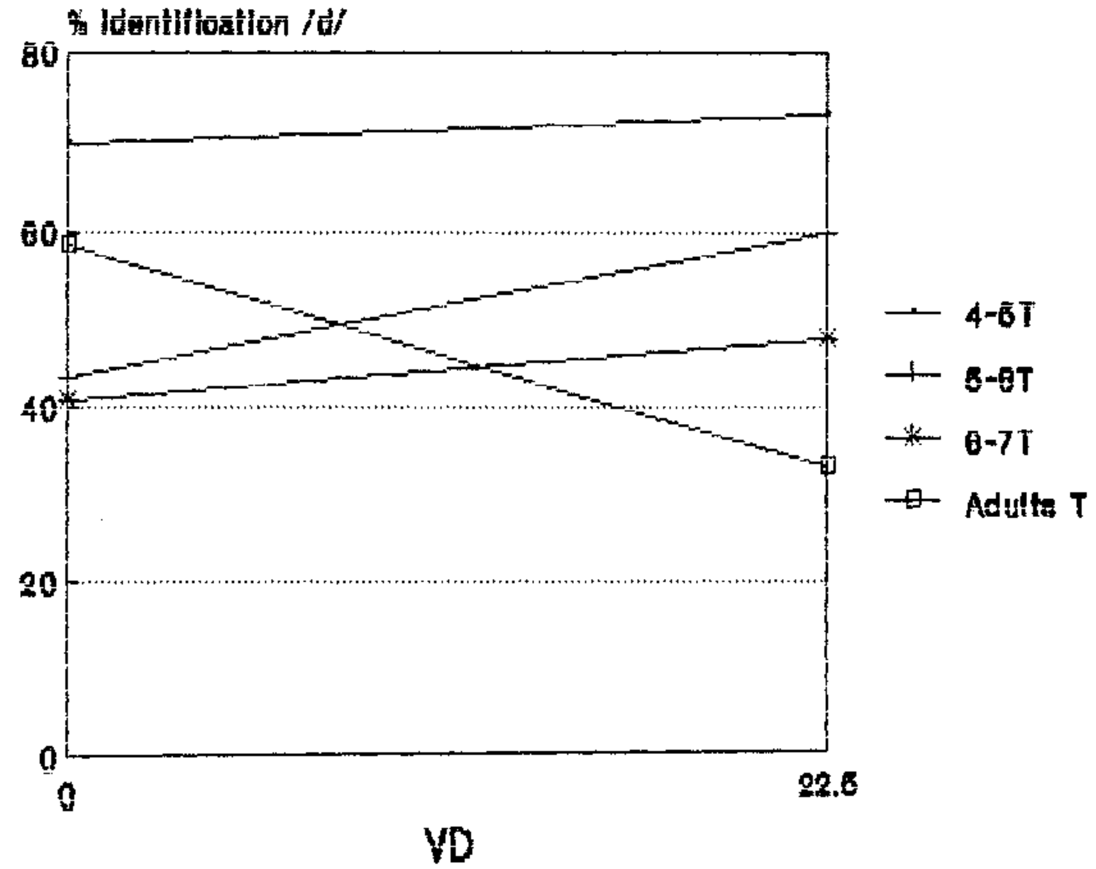


Fig 6.3b: Fereent Identification of /d/ for VDTD

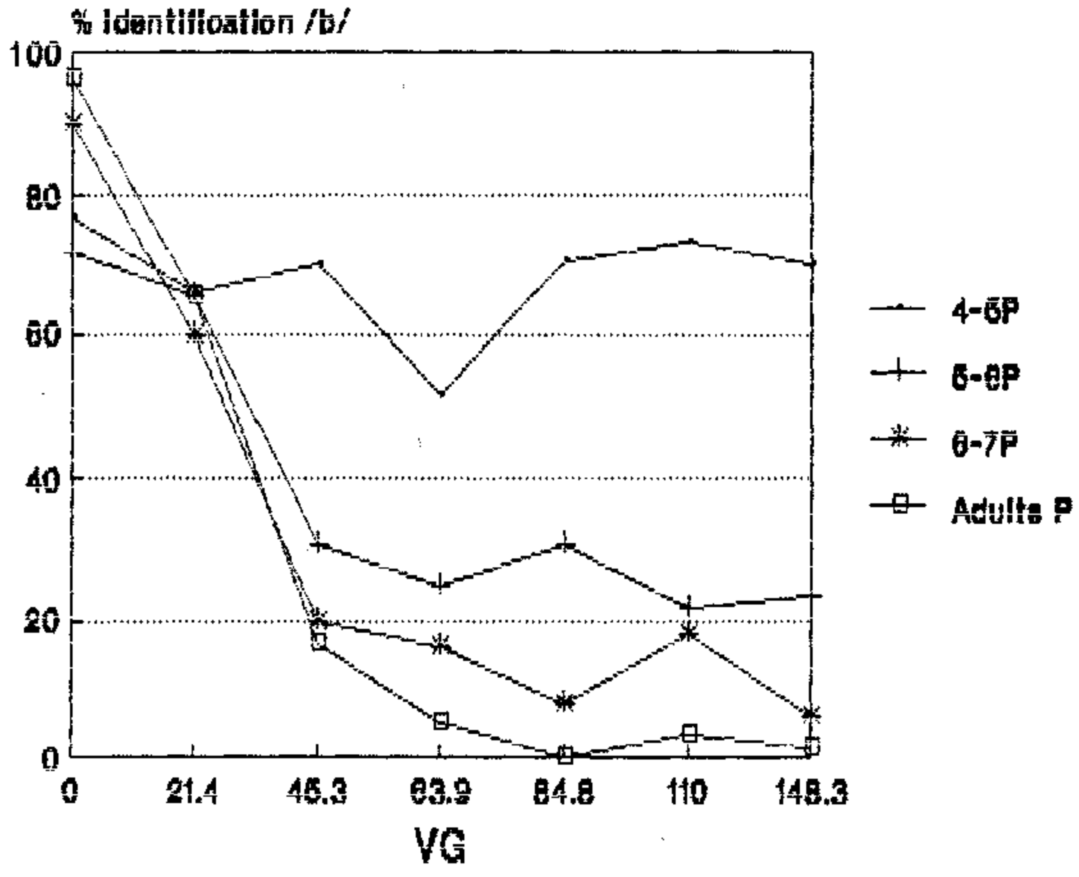


Fig 6.3c: Percent identification of /b/ for VDTD

Stimuli	4-5	5-6	6-7	Avg	Adults
back/bag	-		-	–	25.1
bat/bad	-		-		19.0
cap/cab	-	57.0	64.4	60.7	40.3

Table 6.10: The upper limit of the phoneme boundary for voicing duration & transition duration (VD+TD).

Continuum	4-5	5-6	6-7	Avg	Adults
k-g	-	-	-	-	19.9
t-d	-	-	-	-	13.3
p-b	-	43.8	48.6	47.0	22.2

Table 6.11: The Boundary width for children and adults for (VD+TD).

EXPERIMENT VIM:

50% CROSS OVER: In general it was noticed that 50 % cross over points increased from the age of 3 years to 7 years and further in adults only for velar and no definite developmental trend was observed for retroflex. Among the place of articulation retroflex exhibited longer 50 % cross overs both for children and adults. No subjects in any age group showed 50 % cross over for bilabial (Table 6.12). On comparing the data of children and adults, it was found that adults showed longer 50 % cross over values than children (Table 6.13). However, this was not significant statistically (Mann Whitney at 0.05 level). Also, no significant difference was observed between the 50 % cross over of single and multiple cue conditions.

Continuum	4-5	5-6	6-7	Adults
k-g	0	3	2	4
t-d	0	1	1	2
p-b	0	0	0	0

Table 6.12: Number of subjects who reached 50 % cross over.

Stimu1i	4-5	5-6	6-7	Avg	Adults
back/bag		190.6	191.3	190.9	193.7
bat/bad		217.0	182.0	199.5	210.4
cap/cab	—	-		—	

Table 6.13: Mean of 50% cross over points (in m.secs) for preceding vowel duration & transition duration (PVD+TD).

LOWER LIMIT, UPPER LIMIT & BOUNDARY WIDTH: No specific trend was noticed in Iower limit, upper limit & boundary width in children as no 75 % cross over could be located (Table 6.14, 6.15 & 6.16).

Stimu1i	4-5	5-6	6-7	Avg	Adults
back/bag	-		180.0	180.0	185.6
bat/bad	-		-	-	—
cap/cab	-	-	—	—	-

Table 6.14: Lower limit of phoneme boundary (in m.secs) for preceding vowel duration & transition duration (PVD+TD).

Stimuli	4-5	5-6	6-7	Avg	Adults
back/bag		195.5	-	195.5	205.8
bat/bad		224.5	224.5	224.5	222.0
cap/cab		-	-		

Table 6.15: The upper limit of the phoneme boundary for PVD+TD.

Continuum	4-5	5-6	6-7	Avg	Adults
k-g		-	-		20.2
t-d		-			-
p-b		-	-		

Table 6.16: The Boundary width for children and adults for preceding vowel duration & transition duration.

DISCUSSION

In the multiple array of temporal cues (CD, PVD & VD along with TD substitution), CD+TD emerged as a strong cue for medial stop voicing and VD+TD as a cue for final stop voicing in Kannada language.

The finding that CD+TD and VD+TD is a cue for voicing is in consonance with studies which have specified multiple temporally distributed cues to phonetic distinctions (Repp, etal.1978, Dorman and Raphael, 1980, Dorman etal.1980, Bailey & Summerfield, 1980, Raphael, 1981). However, the finding that PVD either in single cue/multiple cue condition is not a cue for voicing for final stops in Kannada is in contradiction with the results of several studies in English (Raphael ,1972; Raphael ,etal .1975; Lehman & Sharf 1989, Crowther & Mann 1990). It was observed that TD was a cue in combination with CD and VD but not in isolation (Experiment II) or in combination with PVD.

CD in isolation was a strong cue for voicing of stop consonants in medial position and VD and TD in isolation did not emerge as a voicing cue in final and initial position respectively. When TD combined with CD or VD, a cooperating condition was generated thus enhancing the voicing cue. This might be the reason for the shifting of the percept at an early CD+TD in multiple cue condition.

A clear developmental trend was observed for velar and dental for CD+TD in that the boundary width decreased with an increase in the age. However, no such trend was observed for VD+TD substitutions. This result is in consonance with that of Nittrouer & Studdert Kennedy (1987), Nittrouer etal (1989) where they report a clear developmental trend for CD+TD. However, it contrasts the results of Nittrouer & Studdert Kennedy (1987), Nittrouer etal (1989) in that they reported a developmental trend for VD+TD and in the present study it was not so.

It was observed that children used multiple cues to a greater extent than adults which was in contrast with the findings of Robson, Morrengiello, Best and Clifton (1984). On comparing the data of CD+TD between single and multiple cues, it was found that the 50 % cross over values of the multiple cues in the children were higher, that is of about 15-2Omsec than single cues which was statistically significant. In contrast, an analysis of adult data indicated that the 50 % cross over values was higher for multiple acoustic values by 10-15msec compared to single cues. However, this was not statistically significant.

The results support the notion of Greenlee (1978,1980) that children perform more accurately when they are presented with stimulus that vary in more than one dimension.

The boundary width of CD+TD was larger for children than for adults indicating that fine tuning is developed as one grows. When the single cues and multiple cues were compared, it was found that there was an increase in boundary width in children and the adults showed a decrease in the boundary width. Both children and adults showed lesser boundary width for retroflex and dental.

The results revealed that 4-5 years old children did not exhibit 50 % cross over in isolation and in multiple cues for PVD and VD. This could be attributed to the fact that the younger children needed more acoustic differences in order to make perceptual differences.

Children and adults did not respond to PVD or PVD+TD suggesting that the cue may be language specific and PVD may not be a linguistically relevant cue for voicing in final stops in language and hence does not aid in voicing perception. Also, the fact that the children perform better under multiple cue condition than single cue implies that, children may not be finely tuned to the specific acoustic cue and may rely on multiple cues which is not so in adults.

No significant developmental trend was noticed for the parameters VD and PVD in isolation or in combination implying that Kannada speakers may not be tuned for any cues to stop consonants in the final position, as a final stop does not occur in Kannada language. Even a borrowed word with final stop consonant is uttered with an addition of vowel by a Kannada speaker. Given these, a Kannada speaker might use the other cues such as closure duration than PVD & VD which is a must for an English speaker as no other cues are available for a final stop.

To conclude, it appears that children and adults do use CD+TD as a strong cue to differentiate voicing in the medial position. In final position, VD+TD may be used as a cue to differentiate voicing. In contrast PVD+TD does not act as a cue to differentiate voicing in the final position. A clear developmental trend was observed for CD+TD and children attained an adult like pattern at the age of 7 years for all the multiple acoustic cues (CD+TD, PVD+TD and VD+TD).

CHAPTER VII

GENERAL DISCUSSION

SPEECH PRODUCTION:

This study was carried out to investigate the parameters that distinguish voiced and voiceless stop consonant consonants in Kannada language in initial, medial and final position. Also, the developmental nature of the temporal features and their acquisition and effective use in children were examined. The mean, range and category separation scores were analyzed and the results revealed several points of interest.

Firstly, in the initial position, the research on speech development in children has indicated VOT as an important temporal feature to distinguish voicing. It was observed that voiced stop consonants were characterized by lead VOT and voiceless stop consonants by lag VOT. In the voiceless stop consonant a VOT lag was observed due to transglottal pressure drop and the initiation of voicing is after the burst release. The transition duration of the following vowel for the initial stop consonants could not be used to differentiate voicing in stop consonants for both children and adults. However, the place of articulation is clearly depicted in the formant transitions. This suggests that the direction of the transition would be very important for the differentiation of place of articulation.

Secondly, in the medial position, children and adults mainly use closure duration to differentially produce voiced and voiceless stop consonant consonants where the voiced stop consonants exhibited shorter closure duration and the voiceless stop consonants exhibited longer closure duration.

Third, in the final position, vowels preceding voiced stop consonants were longer than those preceding voiceless stop consonants and PVD does not aid in differentiating voicing in final stop consonants.

Fourth, the range of CD increased and that of PVD and VOT decreased from the age of 4 years to 7 years and further in adults indicating a developmental trend and it appears that as children grow their articulation becomes more precise hence follow more adult like pattern. This also indicates that the adults have a narrower range and can differentiate the voicing contrast better than children and also children learn to finely tune the temporal feature as the age progressed.

Fifth, the upper limit for VOT and CD increased and decreased for PVD from the age of 4 to 7 years.

Sixth, the S- ratio of VOT increased in adults when compared to children which indicates that the voicing contrast is better in adults than children. Adults mainly use VOT as a cue to differentially produce voiced-voiceless stop consonants in the initial position but children may use VOT along with other spectral cues. The category separation score "S" was high for both CD & PVD in medial and final position which shows that these parameters can differentiate voiced stop consonants from voiceless stop consonants. But on comparing the S-ratio of PVD & CD it was found that S ratio was stronger for CD than for PVD indicating that PVD may not be a strong parameter distinguishing voiced and voiceless stop consonants.

Cessation of voicing was observed in children for velars and dentals. Studies on aerodynamics of stop consonants (Mueller & Brown 1980) revealed that cessation of voicing in voiced stop consonants occurs when the subglottic pressure equals that of the supraglottic pressure. The equalization of pressure can be brought about by several mechanism which may act independently or collectively. The mechanisms which facilitate voicing are of two types (a) glottal and supraglottal articulatory adjustments and (b) internal laryngeal adjustments. In children, owing to smaller vocal tract, the pressure equalization occurs at earlier time leading to cessation of voicing.

An interesting finding of the present study was that the 5-6 years old children exhibited higher values than the other age groups. Several authors Hurlock, 1968, Joseph, Laurie, Braga, 1972, Greene 1972) have reported that the age between 5-6 years is a period of transition for children. In this age range, several anatomical and psychological changes have been reported which is in turn reflected in poor performance in all the activities like writing and others skills when compared to adults. In this age children see themselves as incompetent in comparison with adults, and they are realistically so. But their inability to always cope with the demands of adults reinforces their feelings of incompetence. In deference of their own position and in fear of progressing into the increasingly demanding adult world, chiIdren may behave in a way that might seem less mature than before, (Joseph & Laurie, Braga 1974). Also between the age of 5-6 years, children's writing skill is reported to be slow, laborious and very poor (Hurlock 1974). Physiologically the change in the pitch has been reported by Negus, (194fi.), that is the voice of the child of 5 years loses the piping pitch of the first years and the child's speaking voice settles under the influence of the environment at a median pitch in the region of middle C, or may be 2 or 2.5 semitones higher.

SPEECH PERCEPTION:

This study has helped to delineate the voicing cues for perception of initial, medial and final stop consonants in Kannada language. Out of the array of cues on the temporal dimension, one could identify generally sufficient cues of voicing and those which cue only when used in combination. Also, the developmental nature of the cues and their acquisition and effective use in children were examined. The differences in the perceptual phoneme boundary width, limits of PBW and 50% crossover were analyzed across the place of articulation. Differential use of multiple cues and single cues and the perceptual weighting of the cues in Kannada speaking children and adults resulted in several interesting findings.

First of all, the initial position, as has been studied rather extensiveIy [the most well developed approach to describing voicing contrast], VOT (Lisker and Abramson, 1964, 1967, 1970] emerged as a generally sufficient cue for voicing. However, the finding that the shift in percept [50% cross, LL and UL] occurs in the lead region of VOT is language specific to Kannada and is not reported elsewhere (Expt.I). The Transition Duration of the following vowel for initial stop consonant, however, did not seem to carry any perceptual weight as was evident by failure to change the percept in both adults and children for the cues (Expt. II).

An interesting result was that the 50 % cross over occurred in the lead VOT region. While it occurred in the lead region of -14.3 to -19 msec for children, adults showed the cross over between -5.4 to -18.6. A comparison of the 50 % cross over points as obtained by various studies is in Table 7.1.

Author	Year	Language	50 % cross over in m. sec
Yeni-Komshian et.al	1967	English	35
Lisker & Abramsom	1967	Thai	-20 *
Simon	1974	English	15-20
Zlatinet.al	1975	English	>25
Williams	1977	English	+25
		Spanish	-4 *
Williams	1980	English	>15 (4-8yrs)
			19 (7-10yrs)
			25 (adults)
Flege & Eefting	1986	English	36.2
		Spanish	19.9
Sathya	1996	Telugu	-10 (children)*
			-20 (adults) *
Present study	1996	Kannada	-16.8 (children
			-10.7 (adults)

Table 7.1: 50 % cross over values as obtained by various authors.

Williams (1977) speculated that Spanish listeners give greater weight to prevoicing as a cue to voicedness than English listeners and greater weight to the presence of an audible release burst & the lack of low frequency energy immediately following it, as cues to voiceless. The finding of Williams (1977) that the category boundary between /b/ & /p/ occurred along a VOT continuum occurred around -4 msec for Puertoricans who were monolingual Spanish speakers suggest that the phonetic processing of speech may be slowly attuned to the acoustic properties of stop consonants found in a particular language (Aslin & Pisoni ,1980). Flege & Eefting (1986) imply that cross language research suggests that speakers of different languages may learn to perceive stop consonants differently because they are exposed to different kinds of stop consonants. Further, English language environment listeners tend to identify both /b/ & /p/ as the phoneme /b/ & the prevoiced/voiced, contrast is physiologically irrelevant in English. This contrast is perceived categorically in other languages ;- for eg- Hindi, Spanish & Thai (Burnham, Earnshaw & Clark, 1991).

Williams (1980) says that in addition to VOT, there are three additional acoustic properties that vary in degree across part of the synthetic speech series. These variations are restricted to the voicing lag region of the continuum:

1. The presence, absence or varying duration of aspiration or aperiodic energy In the interval between articulatory release and the onset of voicing. The presence of aspirated formants is an acoustic property that has been demonstrated to provide a positive cue for initial voicelessness to English listeners (Winitz etal,1975).
2. The absence of periodic acoustic energy at the level of F1 during aperiodic excitation of the vocal tractpreferred to as first formant cut back (Liberman etal 1958). There is also evidence that the presence or absence of periodic energy in the region of F1 provides a perceptual cue for an initial contrast in voicing for English listeners (Delattre etal 1955, Liberman etal 1958 and Lisker 1975).
3. Differences in the degree and temporal extent of formant transitions under conditions of periodic excitation of the

vocal tract. There is some evidence that this acoustic variable may also provide a cue for initial voicing in English (Cooper etal 1952, Stevens & Klatt 1974, Summerfield & Haggard 1974).

On examination & comparison of spectrograms of /b/ & /p/ taken for Kannada with those provided by Williams (1980) reveals that the stop consonants in Kannada are entirely different than that of English in all the three parameters listed above . Neither aspiration in the lag VOT region, nor F1 cut back is present. These differences in the acoustic properties of stop consonants in English and Kannada might be reflected in the perception also with a 50 % cross over in the lag VOT region for English and lead VOT region in Kannada.

Also, while in the other studies the syllables have been synthesized using the Klatt synthesizer, in the present study waveform editing of natural stimuli has been performed. However, the waveforms are without any extraneous noise as seen on the spectrograms and the results are comparable to those of the earlier studies involving languages which contrast voiced and unvoiced by lead and short lag VOT.

This result that 50% cross over occurred in the lead region which is not in consonance with studies in English language for the same reason. While in English a contrast between lead and lag VOT's are depicted, in the present study a contrast between lead and short lag VOT's are depicted. In

3-way or 4-way category languages like Kannada which resemble Telugu, Spanish, Thai, it appears that the crossover occurs in the lead VOT region. While in Telugu, it occurred around -10 msec in children and -20 msec for adults, in Kannada it was around -17 msec in children and -11 msec in adults, in Thai at around -20 msec (adults) and in Spanish at -4 msec (adults). While in Telugu, adults identify voiceless stop consonants at longer VOT's than children, in Kannada adults identify voiceless stop consonants at shorter VOT's than chiIdren.

While comparing the discrimination data obtained from adult speakers of Thai and English for synthetic bilabial stop consonants, Aslin & Pisoni (1980) comment that "the relative discriminability in the -20 msec of voicing lag in greater than in the -20 msec region of the voicing lead despite the fact that the slopes of the labelling functions for Thai subjects in these regions are very nearly identical. They propose that the smaller incidence of discrimination of VOT (and TOT) differences in the minus region of voicing lead value is probably due to the generally poorer ability of the auditory system to resolve temporal differences in which a lower frequency component precedes a higher frequency component" (for unvoiced stop consonant and lower frequency component - voicing - precedes a higher frequency component for - burst release - for voiced stop consonant).

Aslin & Pisoni (1980) further commenting on infant studies on VOT suggest that "The discrimination of the relative order between the onset of first formant and higher formants (Pisoni, 1977) is more highly " at certain regions along the VOT stimulus continuum corresponding roughly to the location of the threshold for resolving these differences Psycho-physically. In the case of temporal order processing, this falls roughly near the region surrounding +. 20 msec, a value corresponding to the threshold for temporal order processing (Hirsh, 1959)".

Further commenting on Pisoni's (1977) experiment on TOT (Tone onset time), Aslin & Pisoni (1980) say that "two distinct regions of high discriminability are present in the discrimination functions. Evidence of discrimination of VOT contrasts that straddle the -20 and +20 msec regions of the stimulus continuum probably results from general sensory constraints on the mammalian auditory system to resolve small differences in temporal order and not from phonetic categorization.

This might be possible, as the wide differences obtained in the category boundaries for various languages varied from -4 to -20 msec (which is more than one stimulus -10 msec - along the VOT continuum). Also, in Kannada it varied from -14 to -19 msec for chi Idren and -5 to -19 msec for adults for various places of articulation. All these variations are within 20 msec.

Three views regarding the differences in perception of voicing contrast in various languages are held (Burnham & Earnshaw 1991). (1) Phonetic contrasts in languages have evolved to take advantage of the natural psycho-acoustic abilities inherent in the human auditory system rather than the other way round (Kuhl, 1978). (2) Contrasts differ in their degree of robustness or perceptual salience and (3) the more perceptually salient a particular contrast, the more likely it is to have been favored in the evolution of the world's languages (Burnham & Earnshaw, 1991). In Kannada, the contrast of voiced/voiceless unaspirated in perceptually salient which is depicted in the result that 50% cross over is occurring in the lead VOT region. It is possible that two category boundaries might be obtained if voiced unaspirated, voiceless unaspirated and voiceless aspirated are contrasted. It would be interesting to study a language like Tamil where phonemic contrast between voiced and unvoiced are not existing.

A comparison of the speech production and speech perception data (Table - 7.2) indicates no one to one relationship between production and perception. While in speech production, the voicing of stop consonants are well contrasted with the voiced stop consonants demonstrating lead VOT and the voiceless stop consonants demonstrating lag VOT, in speech perception task, though children reveal abilities to discriminate between the two, children and adults identified the tokens with short lead VOT (less than 20 msec) as voiceless stop consonants.

		k	g	t	d	P
VOT	Children	L	LL	L	SL	L
	Adults	L	SL	L	SL	L
50 % Crossover	Children	L	L		L	
	Adults	L	L		L	

Table 7.2: VOT type in speech production and speech perception
LL: Long lag SL: Short lag L: Lead

While in speech production task, VOT decreased from 4-7 years, in speech perception task the 50% cross over appears to shift from longer lead VOT's to short lead VOT's. Also, longer VOT's and higher 50% cross over were observed for velar in both children and adults.

Another interesting result was that the boundary width decreased from 4 to 7 years of age indicating that the children could make a finer distinction between the voiced and the voiceless cognates. A comparison of S-ratio and boundary width between children and adults (Table - 3.15) reveal that, in adults S-ratio increases and boundary width decreases for all pairs of stop cognates. Also, this comparison indicates that children even at the age of 7 years do not attain adult like patterns. This data reflects a distinct production of voicing contrasts (high S-ratio) and a finer discrimination ability (narrow boundary widths) in adults.

		Children	Adults
k-g	S-R	103	113
	B.W.	34	25
t-d	S-R	87	100
	B.W.	29	26
p-b	S-R	74	104
	B.W.	25	13

Table 7.3: S-Ratio & boundary width in children and adults (in msec)

The data reveals a definite shift in perception from voiced to voiceless cognates for all the three continuum considered. Based on the above findings, it could be concluded that VOT acts as a cue in voicing distinction in Kannada Ianguage.

Children as younger as 4-5 year age group are able to distinguish voiced/voiceless category using temporal parameter VOT. This is in consonance with the results of the study conducted by Zlatin & Koenegsknecht (1974). While testing, some subjects exhibited several kinds of responses during decision making task, even though alternate forced choice paradigm was used. Quizzical expressions were noticed particularly when the decision involved a stimulus which fall in their own boundary region. Multiple cross over points were observed more in the younger age group. During perception task, the four year old children displayed anticipatory behaviour. They would simply repeat the words prior or during the stimulus presentation.

These individual responses reflect the variations in maturity among children. Children in the age group of 5-6 years show entirely different responses than the children in the other age groups. The reasons for this might be that the age between 5-6 years is a transitional period as they enter the school. Several anatomical and psychological changes take place in this age (Hurlock, Joseph etal 1972, Greene 1972).

Second, in the medial position, the Closure Duration proved to be a generally sufficient cue in both isolation (Expt.III and VI) and in combination. While shorter Closure Durations cued voiced stop consonants longer closure durations cued unvoiced stop consonants.

Third, the final position, certain contradictory results were obtained. A particularly striking result was that PVD in isolation or in combination with Transition Duration and VD in isolation was not a cue for voicing of final stop consonants. Due to non-occurrence of stop consonants in the final position, native Kannada speakers may not be tuned to PVD and VD which is a non-native contrast cue.

Fourth, significant differences in the measures of 50% cross over, limits of phoneme boundary and phoneme boundary width existed as a function of age for VOT, CD, CD+TD and VD+TD. The 50% cross over, LL and UL increased with age and the PBW decreased with age. This finding is in consonance

With the results of the studies conducted by Wolf, 1973; Zlatin and Koenigsknecht, 1976; Ohde and Sharf, 1988. Zlatin and Koenigsknecht (1975) also found that boundary width decreased with increasing age for four different VOT continua especially between 2 year old children and adults.

Fifth, there was evidence of decrease in multiple crossover as the age increased. While at the age of 4-5 years end point responses are categorical (Zlatin, and Koenigsknecht, 1975; Simon and Fourcin, 1978) and in older children and adults, curves are progressively steeper with clear category boundary.

Sixth, it was observed that children's performance becomes more accurate (and therefore more categorical) when a number of acoustic features co-operate under multiple cues condition as it was found for both closure duration and voicing duration in combination with TD . Closure duration shorter by 15-20 msec, was required for 50% cross over. Also, phoneme boundary width were less in multiple cue condition than in isolation only for adults. Abbs and Minifie (1969), Greenlee (1978) and Simon and Fourcin (1978) have found similar results both in children and adults. This analysis indicatesthat cooperating cues might result in better perception. The voicing distinction in both conditions CD+TD and VD+TD was facilitated by transition duration substitution.

Although children performed better when they were presented with stimuli varied along more than one dimension, for CD+TD and VD+TD, the same was not true with PVD+TD. This implies a language specific effect. PVD+TD is an acoustic attribute of the speech signal which is not criteria! in Kannada language as evidenced by Experiment IV and VII. Thus, it could be inferred that cues may differ in value across language and only linguistically relevant cue would be expected to aid in phoneme perception. For the cues CD+TD and VD+TD although children did use combination cues better than single cues, they did not reach the adult pattern. It is apparent that the development is not sufficiently advanced in the effectiveness with which the cue is being used. Also, there is differential use of specific acoustic characteristics as a function of age.

In the light of the above findings, it appears that articulatory and perceptual development is a significant factor for speech. There is an increase in specificity in acquiring information from stimuli presented and acoustic cues available.

A comparison of the results of experiments on Speech production and Speech perception indicates a relationship between the two. While the S-ratio increases with age indicating differential production of the voiced and unvoiced, Boundary width decreases indicating reduction in confusions in the perception of voiced and unvoiced. These results support the notion that speech production and perception are related to each other.

An audio-cassette has been prepared based on the results. The cassette consist of synthetic stimuli for VOT, CD, CD+ TD. THIS CAN BE USED WITH THE CLINICAL POPULATION AS A DIAGNOSTIC TOOL FOR SPEECH PERCEPTUAL ABILITIES.

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I

APPENDIX

LIST OF SYNTHETIC STIMULI IN THE TEST TAPE

ORDER IN WHICH THE SYNTHETIC TOKENS OF /A:KI/ HAVE BEEN ARRANGED

FOR CLOSURE DURATION

playbat 1(/fp\sc /fdz1 3 /fdko 3 /fdki0 3 /fdk20 3 /fdk30 3 /fdk40 3 **/fdk50** 5)

playbat 1(/fp\sc /fdz2 3 /fdk10 3 /fdk30 3 /fdko 3 /fdk50 3 **/fdk20** 3 /fdk40 5)

playbat 1(/fp\sc /fdz3 3 /fdk30 3 /fdkS0 3 /fdko 3 /fdk20 3 /fdk40 3 /fdki0 S)

playbat 1(/fp\sc **/fdz4** 3 /fdkS0 3 /fdki0 3 /fdk40 3 /fdk20 3 /fdko 3 /fdk30 5)

playbat 1(/fp\ac /fdz5 3 /fdk20 3 /fdk40 3 /fdko 3 /fdk30 3 /fdki0 3 /fdkS0 5)

OROER IN IHICH THE SYNTHETIC TOKENS OF **/A:T.V** HAVE BEEN ARRANGED

FOR CLOSURE DURATION

playbat 1(/fp\sc /fdz1 3 /fdto 3 /fdli0 3 /fd(20 3 /fdt30 3 /fdU0 3 /fdt50 5)

playbat 1(/fp\sc /fdz2 3 /fdti0 3 /fdt30 3 **/fdto 3 /fdt50** 3 /fdt20 3 /fdt40 5)

playbat 1(/fp\sc /fdz3 3 /fdt30 3 /fdtS0 3 /fdto 3 /fdt20 3 /fdt40 3 /fdti0 5}

playbat 1(/fp\sc /fdz4 3 /fdtS0 3 /fdti0 3 **/fdU0** 3 /fdt20 3 /fdto 3 /fdtS0 S)

playbat 1(/fp\sc /fdzS 3 /fdt20 3 /fdt40 3 /fdto 3 /fdtS0 3 /fdti0 3 /fdlS0 5)

ORDER IN **WHICH** THE SYNTHETIC TOKENS OF /AiTA/ HAVE BEEN ARRANGED

FOR CLOSURE DURATION

playbat 1(/fp\sc /fdzi 3 /fdtho 3 /fdtholO 3 /fdtho20 3 /fdthoJO 3 /fdtho40 3 /fdtho50 5)

playbat 1(/fp\sc /fdz2 3 /fdtholO 3 /fdtho30 3 /fdtho 3 /fdtho50 3 /fdtho20 3 **/fdtho40** S)

playbat 1(/fp\sc /fdz3 3 /fdtho30 3 **/fdthoSO** 3 /fdtho 3 /fdtho20 3 /fdtho40 3 **/fdtholO** 5)

playbat 1(/fp\sc /fdz4 3 /fdthoSO 3 /fdtholO 3 /fdtho40 3 /fdtho20 3 /fdtho 3 /fdtho30 5)

playbat 1(/fp\sc /fdzS 3 /fdtho20 3 /fdtho40 3 /fdtho 3 /fdtho30 3 /fdtholO 3 /fdtho50 5)

ORDER **IN WHICH** THE SYNTHETIC TOKENS OF /A:PA/ HAVE BEEN ARRANGED

FOR CLOSURE DURATION

playbat 1(/fp\sc /fdzi 3 /fdpo 3 /fdpolO 3 /fdpo20 3 /fdpo30 3 /fdpo40 3 /fdpoSO S)

playbat 1(/fp\sc /fdz2 3 /fdpolO 3 /fdpo30 3 /fdpo 3 /fdpo50 3 /fdpo20 3 /fdpo40 5}

playbat 1(/fp\sc /fdz3 3 /fdpo30 3 /fdpoSO 3 /fdpo 3 /fdpo20 3 /fdpo40 3 /fdpolO 5)

playbat 1(/fp\sc /fdz4 3 /fdpoSO 3 /fdpolO 3 /fdpo40 3 /fdpo20 3 /fdpo 3 /fdpo30 5)

playbat t(/fp\sc /fdzS 3 /fdpo20 3 /fdpo40 3 /fdpo 3 /fdpo30 3 /fdpolO 3 /fdpoSO 5)

ORDER IN **WHICH** THE SYNTHETIC TOKENS OF /KADI/ HAVE BEEN ARRANGED FOR VOT

playbat 1(/fp\sc /fdzi 3 /fdKO 3 /fdKI 3 **/fdK2** 3 /fdK3 3 /fdM 5)
playbat 1(/fp\sc /fdz2 3 /fdK4 3 /fdKI 3 /fdK3 3 /fdK2 3 **/fdKO** 5)
playbat **1(/fp\sc** /fdz3 3 /fdKI 3 /fdK3 3 /fdM 3 /fdK2 3 /fdKO S)
playbat 1(/fp\sc /fdz4 3 /fdM 3 /fdK3 3 /fdK2 3 /fdKO 3 /fdKI 5}
playbat 1(/fp\sc /fdz5 3 /fdKO 3 /fdKI 3 /fdK3 3 /fdK2 3 /fdM S)

ORDER IN **WHICH** THE SYNTHETIC TOKENS OF /TADA/ HAVE BEEN ARRANGED FOR VOT

playbat 1(/fp\sc /fdzi 3 /fdTO 3 /fdTI 3 /fdT2 3 /fdT3 3 /fdT4 5)
playbat 1(/fp\sc /fdz2 3 /fdT4 3 /fdTI 3 /fdT3 3 /fdT2 3 /fdTO 5}
playbat 1(/fp\sc /fdz3 3 /fdTI 3 /fdT3 3 /fdT4 3 /fdT2 3 /fdTO 5)
playbat 1(/fp\sc /fdz4 3 /fdT4 3 /fdT3 3 /fdT2 3 /fdTO 3 /fdTI S)
playbat 1(/fp\sc /fdz5 3 /fdTO 3 /fdTI 3 /fdT3 3 /fdT2 3 /fdT4 5)

ORDER IN **WHICH** THE SYNTHETIC TOKENS OF /PADI/ HAVE BEEN ARRANGED FOR VOT

playbat **1(/fp\sc** /fdzt 3 /fdPO 3 /fdPI 3 /fdP2 3 /fdP3 3 /fdP4 5)
playbat 1(/fp\sc /fdz2 3 /fdP4 3 /fdPI 3 /fdP3 3 /fdP2 3 /fdPO 5)
playbat t(/fp\sc /fdz3 3 /fdPI 3 /fdP3 3 /fdP4 3 /fdP2 3 /fdPO 5)
playbat 1(/fp\sc /fdz4 3 /fdP4 3 /fdP3 3 /fdP2 3 /fdPO 3 /fdPI 5)
playbat 1(/fp\sc /fdz5 3 /fdPO 3 /fdPI 3 /fdP3 3 /fdP2 3 /fdP4 5)

ORDER IN **WHICH** THE SYNTHETIC TOKENS OF **/A:KI/** HAVE BEEN ARRANGED
FOR CLOSURE DURATION + TRANSITION DURATION

playbat 1(/fp\sc /fdzi 3 /fdko 3 /fdk2 3 /fdk3 3 /fdk4 3 /fdk5 3)
playbat 1(/fp\sc /fdk8 3 /fdk7 5)
playbai 1(/fp\sc /fdz2 3 /fdk4 3 /fdk5 3 /fdk8 3 /fdkT 3 /fdko 3)
playbat 1(/fp\sc /fdk3 3 /fdk2 5)
playbat 1(/fp\sc /fdz3 3 /fdk3 3 /fdk4 3 /fdk7 3 /fdk5 3)
playbat 1(/fp\sc /fdk8 3 /fdko 3 /fdk2 5)
playbat 1(/fp\sc /fdz4 3 /fdk8 3 /fdk5 3 /fdk2 3 /fdk3 3)
playbat 1(/fp\sc /fdko 3 /fdk7 3 /fdk4 5)
playbat 1(/fp\sc /fdz5 3 /fdko 3 /fdk3 3 /fdkS 3 /fdk2 3 /fdk4 3)
playbat 1(/fp\sc /fdk6 3 /fdk7 5)

ORDER IN **WHICH** THE SYNTHETIC TOKENS OF /A:TI/ HAVE BEEN ARRANGED
FOR CLOSURE DURATION + TRANSITION DURATION

playbat t(/fp\ac /fdzi 3 /fdto 3 /fdt2 3 /fdt3 3 /fdt4 3 /fdtS 3)
playbat t(/fp\sc /fdt6 3 **/fdt7** 5)
playbat 1(/fp\sc /fdz2 3 /fdt4 3 /fdt5 3 /fdt6 3 /fdtT 3 /fdto 3)
playbat 1(/fp\sc **/fdl3** 3 /fdt2 5)
playbat 1(/fp\sc /fdz3 3 /fdt3 3 /fdt4 3 /fdtT 3 /fdt5 3)
playbat 1(/fp\sc /fdt6 3 /fdto 3 /fdt2 5)
playbat 1(/fp\sc /fdz4 3 /fdt8 3 /fdt5 3 /fdt2 3 /fdt3 3)
playbat 1{/fp\sc /fdto 3 /fdt7 3 /fdt4 5)
playbat 1(/fp\sc /fdz5 3 /fdto 3 /fdt3 3 /fdtS 3 /fdt2 3 /fdt4 3)
playbat 1(/fp\sc /fdt8 3 /fdt7 5)

ORDER IN MICH THE SYNTHETIC TOKENS OF **/A:TA/** HAVE BEEN ARRANGED

FOR CLOSURE DURATION + TRANSITION DURATION

playbat 1(/fp\sc /fdzi 3 /fdtho 3 /fdth2 3 /fdth3 3 /fdth4 3 /fdth5 3)

playbat t(/fp\sc /fdth8 3 /fdth7 5)

playbat 1(/fp\sc /fdz2 3 /fdth4 3 /fdthS 3 /fdth8 3 /fdthT 3 /fdtho 3)

playbat 1(/fp\sc /fdth3 3 /fdth2 5)

playbat 1(/fp\sc /fdz3 3 /fdth3 3 /fdth4 3 /fdth7 3 **/fdthS** 3)

playbat 1(/fp\sc /fdth8 3 /fdtho 3 /fdth2 5)

playbat 1(/fp\sc /fdz4 3 /fdth8 3 /fdth5 3 **/fdth2** 3 /fdth3 3)

playbat 1(/fp\sc /fdtho 3 /fdth7 3 /fdth4 5)

playbat 1(/fp\sc /fdz5 3 /fdtho 3 /fdth3 3 **/fdthS** 3 /fdth2 3 /fdth4 3)

playbat 1(/fp\sc /fdth8 3 /fdthl 5)

ORDER **IN WHICH** THE SYNTHETIC TOKENS OF /A:PA/ HAVE BEEN ARRANGED

FOR CLOSURE DURATION + TRANSITION DURATION

playbat 1(/fp\sc /fdzi 3 /fdpo 3 /fdp2 3 /fdp3 3 /fdp4 3 /fdpS 3) playbat 1(/fp\sc /fdpB 3 /fdp7 5)

playbat 1(/fp\sc /fdz2 3 /fdp4 3 /fdp5 3 /fdp8 3 *It dpi* 3 /fdpo 3) playbat t(/fp\sc /fdp3 3 /fdp2 5)

playbat 1(/fp\sc /fdz3 3 /fdp3 3 /fdp4 3 /fdp7 3 /fdpS 3)

playbat 1(/fp\sc /fdp8 3 /fdpo 3 /fdp2 5)

playbat 1(/fp\sc /fdz4 3 /fdpS 3 /fdp5 3 /fdp2 3 /fdp3 3)

playbat 1(/fp\sc /fdpo 3 /fdp7 3 /fdp4 5)

playbat 1(/fp\sc /fdzS 3 /fdpo 3 /fdp3 3 /fdp5 3 /fdp2 3 /fdp4 3) playbat 1(/fp\sc /fdpB 3 /fdp7 5)