PERCEPTION-PRODUCTION IN RELATION TO FRONTING OF VELARS

IN

HINDI AND MARATI SPEAKING CHILDREN

By

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In dedication to

"the little dark cloud which brings happiness"

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ABSTRACT

The study reports the findings of production analysis and perceptual tests of subjects with fronting of velars from Hindi/Marati language backgrounds. The acoustic characteristics of voiceless aspirated velar and dental plosives in normal children and subjects with fronting of velars is reported. The production based acoustic analysis included the measurement of both spectral and durational features both specific to the consonant and segments of the test words. Perceptual tests probed the speech disordered subject's , perception of contrast in adult output, and their own output. Furthermore, it tested the normally articulating children's perception of the output of subject's with fronting of velars.

The results of the perceptual experiments indicated that some velar fronting children demonstrated significant difference in their identification skills compared to adult trained listeners while listening to their own production of the target words. The production analysis revealed that some children maintained significant differences in their word initial voiceless aspirated velar and dental plosive words. The results are discussed in-terms of earlier findings and its clinical implications.

KEY TO SYMBOLS AND ABBREVIATIONS

Most of the symbols used for the analysis of speech sounds in the text to refer to speech sounds follow the International Phonetic Alphabet conventions, except for the following:

Symbols	Representation of
`a'	Unrounded low back vowel.
`t̲'	Dental unaspirated voiceless plosive.

Abbreviations	Explanation
LPC	Linear Predictive Coefficient.
FFT	Fast Fourier Transform.
kHz	Kilo Hertz.
ms	Milliseconds.
SD	Standard Deviation.
F2	Formant two measured in periodic segment.
F2tr	F2 related peak in transient segment.
F2fr	F2 related peak in post-transient segment.
F2as	F2 related peak in aspiration.
F2[a]	F2 of vowel [a].
ILtr	The difference between intensity of the F2 related peak and the lowest energy level between the F2 related peak and 3kHz in LPC average spectrum of transient segment.
IHtr	The difference between intensity of the F2 related peak and intensity of highest energy peak between 3kHz and 4kHz in average LPC spectra of transient segment.
ILfr	The difference between intensity of the F2 related peak and the lowest energy level between the F2 related peak and 3kHz in LPC average spectrum of post-transient segment.
IHfr	The difference between intensity of the F2 relat-

ed peak and intensity of highest energy peak between 3kHz and 4kHz in average LPC spectra of post-transient segment.

ILas The difference between intensity of the F2 related peak and the lowest energy level between the F2 related peak and 3kHz in LPC average spectrum of aspiration segment.

IHas The difference between intensity of the F2 related peak and intensity of highest energy peak between 3kHz and 4kHz in average LPC spectra of aspiration segment.

Dtr Duration of transient.

Das Duration of aspiration.

VOT Voice onset time.

D[a] Durationion of vowel [a].

Dwrd Duration of the entire word.

F0 Fundamental frequency.

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1 Chapter I: INTRODUCTION

Functional misarticulation was for many years used to describe the conditions of individuals whose speech sound production errors cannot be attributed to any obvious organic problems, phonological disorders now being found as an alternative term. Traditionally, their errors have been viewed as difficulties in learning the motor strategies necessary to articulate speech sounds. Application of linguistic techniques and methodologies to normal speech sound acquisition and functional misarticulation indicates that a systematic pattern can be identified in their speech sound errors (Stampe, 1973; Grunwell, 1981; Ingram, 1976). Such observations have lead investigators to conclude that those with so-called functional misarticulations may in fact have a disordered phonology.

1.1 Phonetic Vs. Phonological Disorders:-

From a linguistic point of view speech sounds can be viewed in two ways:-

1) As a sound produced by the human vocal tract which can be subject to phonetic classification,
2) As a phoneme which is the smallest segmental unit of speech which enables meaning to be changed. For example, `pin' /pIn/ and `bin'/bIn/.

A phoneme is represented by a group of speech sounds which are narrowly phonetically different, that is the allophones of that phoneme. For example the two /p/ phonemes in the English word `paper' are different, the first carrying greater aspiration than the second. However, in English these two sounds do not contribute to a change in meaning and hence both are represented by the phoneme /p/. Patterns of allophonic variation are specific to the language in question, so that /p/ has a set of variants in the phonology of English, which does not coincide precisely with those found in the phonologies of other languages, for example Indian languages. The phoneme is viewed to function at an abstract level. <u>Phonetic disorders</u> are presented when a person has difficulty in producing a particular sound. This term has been used in recent years to refer to organic articulation disorders although within the traditional framework, the distinction between organic /functional was not clearly maintained. On the other hand <u>Phonological disorders</u> refer to a speaker's difficulty in the organisation of speech sounds as linguistic units, and hence to a difficulty in their use to signal meaning. In addition a phonological approach involves identifying the underlying patterns in the child's error production (Dinnsen, 1984; Martin, 1989; Ingram, 1981). Linguistic application to functional misarticulations indicates that their error patterns are in fact phonological disorders.

Two opposing view-points have been proposed regarding the nature of the observed phonological errors (Maxwell, 1984). They are:-

1) The individual perceives the phoneme correctly but due to insufficient knowledge of phonological rules or processes produces a surface form which is erroneous. The underlying representations are generally considered to be identical to the normal speaker's surface form (Stampe, 1973; Braine, 1976; Dongar & Stampe, 1979; Ingram, 1971; Menn, 1978; Smith, 1973). The individual's ability to "discriminate" contrasts spoken by normal speakers is often cited as evidence in support of this stand.
2) The individual's underlying representation are not always identical to normal speaker's surface form. Hence, the individual produces surface forms different from normal speakers. Systematic acous tic differences in target sound and substituted sounds are cited in support of this view point (Braine, 1979; Macken, 1980; Kornfeld & Goehl, 1974; Dinnsen, 1984; Maxwell & Weismer, 1982).

Although the latter viewpoint does not directly indict perceptual disorders, there is a strong tendency to consider a disordered perceptual mechanism as one of the possible causes for production errors (Braine, 1979;

Macken, 1980; Kornfeld, 1971). However, research literature indicates that the role of perception in maintaining speech sound production errors is highly contentious.

1.2 Speech Sound Discrimination and Functional Misarticulation:-

Earlier studies mainly relied on speech sound discrimination tasks to establish the relationship between perception and production of error sounds in functional misarticulation. This relationship will henceforth be referred to as "perception-production relationship". Poor speech sound discrimination skills appear to be a common finding in children with severe and multiple misarticulation. However, there are inconsistent research findings regarding the speech discrimination skills of those with fewer misarticulation. Furthermore, there appears to be confusion as to whether speech discrimination errors cause misarticulation or vise-versa (Perkell, 1986; Monnin & Huntington, 1974; Locke & Kutz, 1975). The discrepancies among studies in this area may be attributed to methodological issues such as the experimental task, the stimuli used, the subject, methods of scoring, and so forth (Locke, 1980ab; Atchson & Canter, 1979). Furthermore, the validity of standardised speech discrimination tests for assessing speech perception has been questioned by several researchers (Bountress & Ladeberg, 1980; Bountress, 1981; Locke, 1980a,b). Some of the major criticisms may be summed as follows:-

1) Testing all possible permutations of speech sounds in minimal pair conditions may not be relevant as all sounds are not misarticulated.

2) Most speech discrimination tests do not take into account the context of the error sound, as errors may not be present in certain contexts.

3) Nonsense syllables used as stimuli may test only phonetic discrimination.

4) The `Same-different' paradigm may test skills only at the level of phonetic discrimination.

Generally it is agreed that "discrimination" of natural speech mainly tests peripheral perceptual skills and may not be directly relevant in gaining insight to perception-production relationships in speech production errors. At this stage it is essential to recognise that perception usually contains two aspects -sensation and identification, where sensation would be more closely related to discrimination and identification to classification of speech sounds into phonemic categories (Barton, 1980).

1.3 <u>Categorical Perception and Acoustic Cues</u>:-

The ability of the human ear to segment a continuous speech wave into different speech sounds is one of the marvels of speech communication. The lack of one-to-one correlation between the acoustic wave form and speech sounds is well established. Perceptual experiments using various speech stimuli systematically varying along certain acoustic continua reveals that labelling of speech sounds does not reflect the physical continuum. For example, voice onset time (VOT) is one of the cues differentiating voiced and voiceless consonants in most languages. Empirical evidence indicates that English speaking native listeners will label short VOTs of less than 20 ms as voiced sounds, while VOTs of 30 ms or above are perceived as voiceless sounds. The same listener is unable to discriminate speech sounds differing by say VOTs of 30 ms and 40ms This phenomenon of sudden shifts in perception from one speech sound category to another at certain acoustic boundaries is referred to as the phenomenon of "Categorical Perception". It has been observed that categorical perception is more prominent for consonants than vowels. A plethora of acoustic cues have been identified which effect the categorisation of a variety of speech sounds. These acoustic cues may be temporal (for example, vowel durations, voice onset time, formant transition duration) or spectral (for example, frequencies of formants, presence of periodic and aperiodic signals, spectrum of release burst) in nature. Furthermore, there may be more than one acoustic feature which cue discrimination of the same phonetic feature. For example, both the onset burst spectrum and formant transitions of stop consonants are important acoustic cues for the identification of place of articulation. There is controversy as to which of these is primary to place perception in stops (Liberman, Cooper, Shankweiler, &

Studdert-Kennedy, 1967; Steven & Blumstein, 1978). Although the human ear is unable to perceive the individual acoustic features, they are the basis on which the entire auditory pattern is perceived as a specific speech sound (Ruffin-Simon, 1983).

1.4 <u>Language Specific Cues</u>:-

The critical values of the acoustic features which result in abrupt shifts in speech sound categories is known to vary with the language environment. For example, Lebanese Arabic speakers are known to produce /d/ with a voicing lead and /t/ with a short lag, while in certain circumstances native English speakers may produce /d/ with a short lag and /t/ with a long lag. The Lebanese listener will categorise such English forms of /d/ as being voiceless, while native English listeners will perceive most Lebanese Arabic alveolar stops as being voiced (Preston, Yeni-Komshian, Stark & Port, 1969). The phenomenon of categorical perception which is language dependent, therefore, will interfere with identification and discrimination of speech sounds which are not part of their phonemic inventory. For example, while conducting phonetic transcription of unfamiliar languages the transcriber may confuse unfamiliar phonemes in the language under transcription with some phonemes in his own language. Similar difficulties may occur while transcribing disordered speech, as the child may often produce phonemes not found in the transcriber's language.

1.5 Acoustic Analysis of Child Speech and Speech Perception in Children with "Normal" Articulation :-

The application of acoustic phonetic analysis to "normal" child data indicates systematic differences when compared to adult production although both are "heard" to produce the same speech sound. As an example, children are often found to produce speech sounds with longer durations than adults. This is true for vowels (Kent and Forner, 1979), consonants (DiSimoni, 1974ac; Hawkins, 1973; Weismer, Ellis, & Chicoris, 1979; Kent & Forner, 1980) and consonant clusters (O'Shaugnessy, 1974). It is generally observed that there is greater intra-speaker variability in child speech than adult, which is interpreted as indicating immature motor control of speech mechanisms (Weismer, 1984). This high variability appears to be true in case of VOTs also (Barton & Macken, 1980; Eguchi & Hirsh, 1969; Kent & Forner, 1980). A developmental pattern has been observed for the acquisition of adult like VOT feature (Barton & Macken, 1980). Compared to temporal acoustic features, there appears to be a dearth of literature regarding spectral characteristics of child speech. Formant frequencies of vowels in children are found to be higher than adults, which can be attributed to smaller vocal tract dimensions in children (Bennett, 1981; Kent & Forner, 1979). However, the large intra-speaker variability in child vowel data cannot be explained by these anatomical conditions alone. Such variability has also been observed for fricative spectra (Pentz, Gilbert, & Zawadski, 1979; Weismer, Elbert, Whiteside, 1980). Formant transitions data measured for /w/,/r/ and /l/ production by preschool children reveals slower transitions relative to those for adults (Dalston, 1975). Generally there appears to be strong evidence that child speech sound production is different from those of adult. The question arises as to whether the "normal" child's perception is also different from that of the adult.

1.6 <u>Speech Sound Perception in Children</u>:-

It has been observed that infants as young as one month old discriminate synthetic speech categorically (Eimas, 1971). However, the nature of their categorical perception during the speech acquisition period is not clear. Strange and Broen (1980) observed that children aged 3.5 years demonstrated adult like categorical perception for speech sounds that had been mastered in their repertoire. This finding further reinforces the notion that perceptual boundaries are conditioned by productive values. On the other hand Ruffin-Simon (1983) observed that 2 year old children have not yet learned to label the physical continuum of speech sound in sharply defined categories. These children demonstrated greater confidence in labelling the extreme values of the continuum than intermediate stimuli values. The researcher also observed that there was a gradual trend towards more adult-like categorical perception with increasing age. Since a variety of acoustic features may cue the same speech sound category, there appears to be a developmental preference for certain acoustic cues as compared to other cues (Simon, 1976; Fourcin, 1978). Generally it is agreed that children with normal articulation demonstrate adult like categorical boundaries for the acoustic feature(s) under study.

1.7 <u>Acoustic Analysis Supplemented by Tests of Speech Perception in Children with Functional Misarticulation</u> :- Application of acoustic phonetics to the investigation of misarticulations indicate that the child appears to retain certain acoustic properties of the target speech sound in his/her error production. Children with final consonant omission were observed to maintain longer vowels while producing words with final voiced consonants and shorter vowels for words with final voiceless consonants (Weismer, Dinnsen & Elbert, 1981; Smit & Bernthal, 1983b). A child with severe functional misarticulation was demonstrated to maintain a phonetic voicing contrast in word initial obstruents, that is, VOT of 9 ms for voiced and 43ms for voiceless cognates. However, Speech-language pathologists had perceived all their productions as being voiced (Maxwell & Weismer, 1982). Riley, Hoffman, & Dmico, (1986) reported the presence of conflicting acoustic cues in the minimal pairs with final consonants differing in voicing (pat/pad) and cluster (pats/pat) produced by misarticulating children. These children apparently used appropriate vowel duration for voicing and consonant clusters, but maintained level transition offsets for the first formant (F1) frequency for all productions which is known to cue post vocalic voiceless stop for adult listeners. In terms of spectral features Kornfeld (1971) reported that "normal" children who reduced obstruent+ /l,r,w/ clusters to /w/ demonstrated consistent second formant(F2) differences between "the form of /w/" which resulted from substitution /r/-clusters than that of /l/-clusters. Both forms were, however, transcribed as the same by trained listeners. There are two possibilities for these production differences in the error sounds:

1) The child attempts to produce as close a match as possible to adult targets and as a result acoustic differences occur in the two stimulus words.
2) The child attempts to produce a speech sound which is part of his system but not that of the adult and which the child recognises as functional.

Acoustic analysis by itself favours neither of these explanations as it is not sufficient for two productions to be proved acoustically different. It is also important to demonstrate that these differences are important for the speaker in the context of speech communication (Ruffin-Simon, 1983). In other words the difference is used to signal a change in meaning.

The clinically observed `fis'- phenomenon (Berko & Brown, 1960), where the child appears to perceive a contrast in his own error production which is heard as homophones by the adult listeners, seems to indicate that the child may be utilising the second of the above two possibilities. Kornfeld and Goehl (1974) found that some children could reliably differentiate their /r/ errors from their /w/ productions. These authors suggested that children with /r/ misarticulation may be producing acoustic differences for their /r/-/w/ contrasts. Similar results have been reported for /r/ misarticulators by Hoffman, Daniloff, & Stager, (1983) who concluded that there may be a sub-population of /r/ misarticulating children who acoustically mark their error /r/ and intended /w/ productions in a non-adult manner. However, as these studies did not assess subject's "categorical perception" for the error sound, it is difficult to ascertain the critical values of the acoustic cues. Although other investigators have observed that some children with /r/ misarticulation do not demonstrate sharp categorical boundaries for the /r-w/ continuum (Ohde & Sharf, 1988), small samples and large variability in data makes it difficult to generalise these observations to subjects in other studies. So deviant categorical perception cannot be attributed to the children of Kornfeld and Goehl (1974) and Hoffman et al (1983) whose /r/ misarticulating subjects demonstrated ability to contrast their /r/ error and intended /w/ productions or vise versa.

In order, therefore, to achieve a comprehensive assessment of perception-production relationship in functional misarticulation various aspects of perception and production would have to be assessed. These may include:-

1) The misarticulating child's ability to auditorily contrast target error sounds in adult production.
2) The Misarticulating child's ability to auditorily contrast target and substituted speech sounds in his/her own error production.
3) The nature of the categorical perception for the error and substituted sounds and the acoustic cues which enhance categorical perception in the misarticulating child.
4) The acoustic differences between the error sound and substituted sound in the child's production.
5) Acoustic differences between the target sound production of misarticulators, normal children and adults.

A review of earlier studies reveals that most which explore the perception-production relationship in functional misarticulation have taken up only one or two of the aspects of speech perception and production assessment listed above (Hoffman et al, 1983; Catts & Kamhi, 1984; Smit & Bernthal, 1983ab; Ohde & Sharf, 1988; Rvachew

& Jamieson, 1989; Raaymakers & Crul, 1988). Hence, it remains unclear whether children demonstrating acoustic contrasts in their error production also perceive these differences, thus demonstrating deviant categorical perception. Findings which clarified the relationship between perception-production in several aspects would not only be relevant for developing appropriate therapeutic strategies but would also have implications for understanding speech sound processing in the misarticulating child and acquisition in normal children. Most researchers have investigated perception and production differences in approximant, fricative, clusters and voicing misarticulators (Hoffman et al, 1983; Catts & Kamhi, 1984; Smit & Bernthal, 1983a,b; Ohde & Sharf, 1988; Rvachew & Jamieson, 1989; Raaymakers & Crul, 1988). However, the nature of the perception-production relation in velar misarticulation has not been well explored. Furthermore, perception-production relationships in fronting of velars cannot be generalised from studies focusing on other error patterns (Locke, 1985; Smit & Bernthal, 1983b and Ohde & Sharf, 1988)

1.8 Fronting of Velars:-

Fronting of velars is often observed in the early stages of speech sound acquisition. They also form part of the error patterns observed in many children with phonological disorders. Children who are described as demonstrating fronting of velars appear to replace velars with alveolar articulations, and thus pairs such as `key/tea' and `cap/tap' are apparently homophonic. Furthermore, developmentally the acquisition of velars appear to follow a special developmental pattern from prelingual speech behaviour to true speech.

In a study of normal hearing children from birth to 15 months, it was observed that velar sounds are preferred prior to 6 mths of age and thereafter frequency of alveolars exceed that of velars (Smith & Oller, 1981; Mavilya, 1969). Some researchers have attributed the prevalence of velars prior to 6mths of age to supine posture. However, scientific evidence is not available to confirm this assumption. In true speech it is observed that bilabials and alveolars precede the acquisition of velars (Prather, Hedrick, & Kenn, 1975). This preference for alveolars in true speech has often been attributed to the inherent motor difficulty associated with velars. However, motor factors alone cannot explain this unique pattern of velar acquisition, that is, the presence of velars in prelingual speech and subsequent loss in true speech. It is largely agreed that prior to 6 months of age the child has not yet linked his production to perception (Mavilya, 1969; Smith, 1981). So one could speculate that perception may play a vital role in realising velars in true speech where auditory feedback is important.

A closer look at important acoustic cues for place of articulation of stop consonants indicate that auditory factors may play an important role in their production. By making use of empirical data from several studies Ruffin-Simon(1983) demonstrated that the sequence of development of auditory pattern perception appears to be low to high frequency, temporal to spectral and simple to complex. The acoustic differences in formant frequency transition for bilabial, alveolar and velar stops indicate that the transition pattern differences shift from low to high and from simple to complex (Ruffin-Simon, 1983). Thus for bilabials all the formant transitions have a rising pattern from low to high frequency, while alveolars can be differentiated from bilabials mainly on the basis of F2 transition, which fall from high to low frequency. However, for velar/alveolar differentiation the third formant transition becomes important as the F3 rises from low to high in velars Fig.(2.1.2 page no.57). It must be noted that transition patterns depend upon the vowel environment. In view of the above stated facts related to auditory perceptual development, patterns of speech sound acquisition (velars and alveolars) and existing acoustic phonetic evidence on velar/alveolar stops, a detailed investigation of perception-production relationship governing velar sounds is warranted. The present study investigates the perception-production relationship in misarticulating children who demonstrate fronting of velars in their repertoire. From the results of the two pilot studies conducted, velar misarticulating English children were observed to have difficulty identifying both velars and alveolars in their own tape recorded speech (Appendix I). Such perceptual confusion which has been observed by other researchers exploring /r/ and /s/errors in their experimental group have speculated that this confusion may be due to a broad and imprecise perceptual boundary for the target and substituted sounds (Hoffman, et al, 1983; Raaymaker & Crul, 1988). Furthermore, the results of the pilot study also indicated that there may be acoustic difference in the attempted velar and alveolar initial words by these subjects. This prompts an interest in the nature of perception-production relationship in velar misarticulating children whose native language has more places of articulation for stops. The Indoaryan group of languages including Marati and Hindi have contrastive bilabial, dental, and retroflex stops. Specific acoustic studies on velar misarticulation in these language group are not available in literature. Clinical observation and experience indicate that children often substitute dentals for velars in these language groups. The present study attempts to ascertain whether children with velar fronting speaking an Indian language:-

(1) maintain "critical" acoustic differences between their velar errors and apical sounds.

(2) are auditorily sensitive to their error & apical sounds which have acoustic "critical" differences.

In an attempt to ascertain this information both phonetic transcription and acoustic analysis of error sounds was made. It was felt that such an auditory analysis supplemented with acoustic phonetic data would aid in ascertaining whether the misarticulating child maintains critical acoustic contrasts in his error production. The comparison was made between the replacing sound for target velars and target dental productions. Furthermore, comparisons were also made between the dentals produced by normal children and error sounds of the misarticulating child. Assessment of perception included perception of adult productions and self-perception. Considering the controversy as to the primary acoustic cue to place perception in stop consonants and the results of the two pilot studies conducted by the present investigator (details included in Appendix I), a specific perceptual task was included to assess the relative importance of onset burst spectrum and formant transitions rather than assessment of "categorical boundaries" of formant transitions. Several experimenters have employed splicing-techniques for isolating burst and transition elements of the consonant to ascertain their relative importance in identification of velars and alveolars (LaRiviere, Winitz, & Heriman, 1975; Chapin, Tseng, & Liberman, 1982; Hewlatt, 1988). A "Test battery" approach was adopted to include all aspects of speech sound perception and production so as to answer the following questions:-

1) Do misarticulating children who front velars in their production make acoustic differences in their velar error production and replacing apical stop consonant?

2) Are there acoustic differences in word initial velar and apical stop contrasts produced by velar misarticulating children, and normal children?

3) Do children who front velars in their speech repertoire:-

   a) auditorily contrast velar and apical stops in normal adult repertoire?

   b) auditorily contrast word initial velar and apical stops in their own production?

4) Are there significant differences in identification scores for misarticulators, normal children and adult while listening to minimal word pairs containing velar and apical stops with varying amounts of burst, aperiodic energy and formant transitions?

Due to the controversy as to the perceptual cues for place of articulation, the paucity of studies on the acoustic characteristics of plosives in child production, and the difficulty encountered in formant tracking in child speech, it became necessary to answer two additional questions, Namely,

(1) Is the Stevens and Blumstein template approach (Stevens & Blumstein, 1978; Blumstein & Stevens, 1979) suitable for

identifying aspirated voiceless velar and dental initial words spoken by children? and

(2) Which acoustic measures would maximally distinguish aspirated voiceless velar and dental initial words spoken by children with no speech errors?

In seeking to answer these questions a `baseline' value for comparison with output of subjects with velar error sounds was made.

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2Chapter II : REVIEW OF LITERATURE

Characterisation of the nature of perception-production relationship in velar misarticulating children needs to include information from a variety of different areas. The review of literature attempts to highlight the research evidence related to issues such as (A) acoustic characteristics of stop consonants and the acoustic cue to place of articulation perception in this manner class, (B) the results of acoustic phonetic application to "functional misarticulation" and phonemic perception in `functional misarticulation', and (C) perception of velar/alveolar contrasts and acoustic characteristics of attempted velars in velar fronting children. Considering the paucity of literature on acoustic characteristics of attempted velar and replacing apical plosives, a detailed description and critical review of the limited studies available has been included.

2.1 A) Acoustic characteristics of Stop consonants:-

Stop consonants are produced by the sudden complete closure of the vocal tract and rapid release. The stop consonants vary in terms of place of articulation and voicing. In the English language there are three main contrastive (phonemic) places of articulation for the plosive class of consonants, that is, bilabial, alveolar, and velar, while in the Indoaryan group of language Marati and Hindi there are four namely bilabial, dental, retroflex and velar. Acoustic analysis may focus on measuring acoustic parameters which

(a) perceptually cue the contrast, **or**

(b) are a result of production dynamics.

Since the listener does not utilize all acoustic differences the number of acoustic parameters in (a), would be a subset of (b), in the case of normal adult speakers and listeners. While exploring the perception-production relation in children with phonological disorders, it is vital that the analysis focus on measuring acoustic parameters that reflect production dynamics rather than those known to act as primary perceptual cues for adult listeners alone.

There are several acoustic cues which reflect production differences between velar and apical plosives. The source-filter theory of speech production forms the basis of most acoustic analysis of speech sounds. Initial aspirated voiceless plosives are characterised by an initial release (Transient) followed occasionally by a `frication' and then by the aspiration which leads to periodic portion of the vowel (Fant, 1973). The initial release together with `frication' has often been referred to as the `burst' in reports of studies conducted in the Haskin Laboratory (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; & Cooper, Delattre, Liberman, Borst & Gerstmanet, 1952).

Although one-to-one mapping of articulation to acoustic analysis is not possible, broadly the various segments of plosive may be associated with various articulatory gestures required to produce the plosive, namely transient, frication, aspiration, and vowel transition.

i) Transient analysis:-

The transient has been described by Fant (1973) as "the response of the vocal tract to the pressure release, exclusive of any turbulence effects." Fant,(1973). The source-filter theory of speech production predicts that both the size and nature of the cavity in front of the sound source influence its frequency characteristic. Generally it is observed that the larger the cavity in front of the sound source the lower the resonant frequency response and vice versa. In the case of plosives the sound source is aperiodic and situated at the point of closure (and subsequent release) in the vocal tract. In velars therefore, a larger cavity is formed in front of the source relative to that for dentals. Hence for the transient portion of the velar, frequencies which are lower than those for dentals will be resonated. The predicted high frequency dominance in apical plosives has been incorporated into the alveolar template of Stevens and Blumstein (1978) and the high `loci' calculated by extrapolation of the formant frequencies (Liberman, et al, 1967 & Cooper, et al, 1952). Fant (1973) measured the formant two (F2) in the transient segment and observed higher F2 for alveolars as compared to velars. He also obtained longer transients for velars compared to other plosives. Hawkins (1986) also observed that burst duration is crucial while generating the velar-bilabial continuum, with larger durations for velars.

ii) **<u>Formant transition analysis and spectral information:-</u>** Traditionally formant measurement has been associated with the periodic section of the waveform. Formants basically reflect the vocal tract shape, being its resonant frequencies. The formant transitions have been observed to reflect place of production (Liberman, et al, 1967). The slopes of formant transitions have been demonstrated to vary as a function of the adjacent vowel (Cooper et al, 1952). When the following vowel is [a], F1 transitions have been observed always to rise from a low frequency locus in the transient for both velars and alveolars. F2 transitions usually decrease in frequency with a faster rate of decrease for alveolars compared to velars. The F3 transition is found to be rising in velars and falling in the case of alveolars. Since most of conclusions regarding the importance of formant transition were based on analysis of synthetic speech, Kewley-port (1983) attempted to ascertain whether this was true for natural speech.

Kewley-Port, (1983), examined the acoustic correlates of place of articulation in naturally produced /b, d, g/. the study focussed on the temporal and spectral measurements of the formants derived by Linear Prediction Analysis

(LPC). The LPC technique was employed as it provides "a much finer temporal resolution of the rapidly varying formant transitions than that obtained from spectrograms" (p380). The results indicated that most transition parameters were not reliable acoustic correlates of place except for F2 transition and a two dimensional representation of F2 X F3 onset frequencies. This was in contradiction to findings reported by Fant (1973) for Swedish consonants.

The findings that the short term spectrum of the first 26ms of a stop consonant yields unique spectra for different places of articulation independent of the following or preceding vowel has stimulated considerable interest in spectral differences for place of articulation (Stevens & Blumstein, 1978, Blumstein & Stevens, 1979; Lahiri, Gewirth, & Blumstein, 1984). Based on theoretical considerations, Stevens & Blumstein (1978) developed templates to categorise bilabial, alveolar, and velar onset spectra sampled at the discontinuity in the acoustic signal which are independent of the vowel environment (Fig.2.1.1).

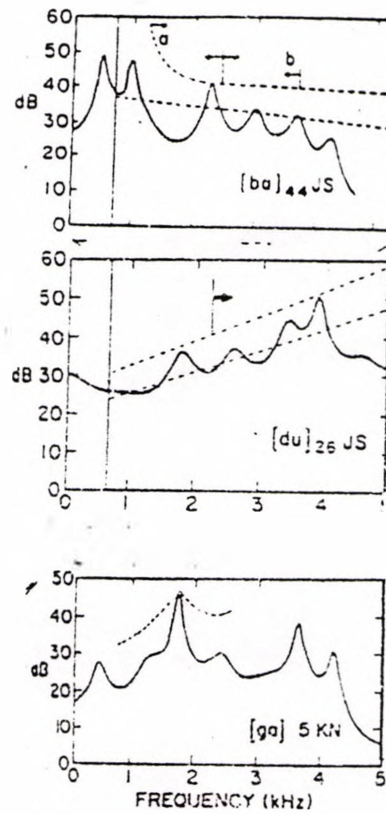

Fig 2.1.1:- Onset spectra for various places of articulation (thick line), devised by Stevens and Blumstein (1978). The templates are indicated by the dotted lines.

iii) Voice onset time and other co-articulatory features:- In addition to the above mentioned acoustic parameters, the velar and alveolar plosive may influence the voice onset time (VOT), with smaller VOT for alveolars than velars, and the following vowel in terms of its length and the spectral characteristics (Lisker & Abramson, 1964; Fant, 1973; Kewley-Port, 1983).

There are several acoustic cues which contribute to the perception of stop consonants such as the frequency peaks of the release burst, and duration of formant transition. In English the burst duration varies from 5-15 ms while the transition duration is 20 - 40 ms. (Liberman & Blumstein, 1988). Early research on acoustic cues considered the formant transitions as the most important acoustic cue for the perception of place of articulation in stops. (Liberman et al, 1967). However the actual frequencies at which bursts occur and the slopes of formant transitions vary as a function of the adjacent vowel (Cooper et al,1952). Typically spectral characteristics of stop consonants differing in place is shown in Figure 2.1.2.

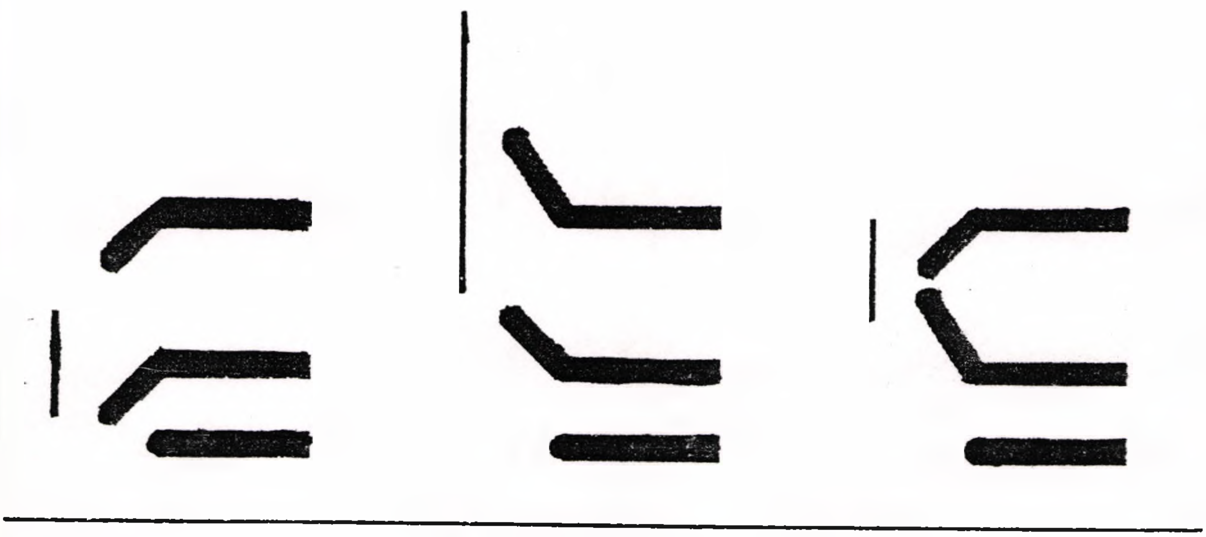

Fig.2.1.2:- Diagrammatic presentation of formant transitions and transients for the syllables [pa, ta ,ka].

Findings indicate that the burst, aperiodic energy and transitions may form a single integrated cue for place information in stops independent of the preceding vowel (Stevens and Blumstein, 1978; Blumstein and Stevens, 1979, 1980). Thus there appears to be two important cues for place of articulation in stop consonants.

a) Onset spectrum of the initial 26ms of the stop.

b) The second and third formant transitions.

Stevens and Blumstein (1978) have proposed that the onset spectrum provides the primary basis for differentially identifying place of articulation for stop consonants by adult listeners. The formant transitions are considered to constitute secondary context dependent cues to place of articulation in stops which may be used in the absence of primary onset spectrum cues, for example unreleased stops. Generally the main functions of the formant transitions are considered to be for providing a smooth and continuous change between onset spectrum and the adjacent vowel (LaRiviere, Winitz, & Heriman, 1975; Stevens and Blumstein, 1978; Blumstein & Stevens, 1979, 1980). Generally, the velar plosive appears to prove itself as an exception to the rule while formulating a theory of acoustic cue for place of articulation in stops. Several investigators have pointed out that acoustically the velar stop is more variable than other stops (Fant, 1973; Hawkins, 1986a). There appears to be greater subject variability in the acoustic feature which provides acoustic cue to velar place of articulation. From the results of perceptual experiment and acoustic analysis of natural velars, Hawkins & Stevens (1987) concluded that a velar stop is heard in CV syllables with steady state formants, if the burst has a mid-frequency spectral peak with an amplitude at least as great as that of the corresponding peak at vowel onset. Thus the "invariant acoustic cue" to place of articulation may be relational in nature rather than absolute measures.

Researchers have also claimed that the onset spectrum cues are developmentally used prior to formant transition cues and sensitivity to this cue is innate (Eimas, 1974; Moffitt,1971; Morse,1972; Williams & Bush, 1978; Stevens & Blumstein ,1978). However, the application of Blumstein-Stevens templates to child speech and perceptual experiments to establish the developmental importance of the two acoustic cues for place of articulation in stop consonants appear to contradict the above conclusions.

Chapin, Tseng, & Liberman,(1982) applied the Blumstein-Stevens templates to categorise the stops in word initial positions produced by 18 mths old children. The overall correct categorisation rate for the templates was 65% with 70% for the bilabial templates, 85% for alveolar templates and 40% for velar templates. It must be noted that the low overall correct score and poor scores for velars did not indicate the absence of place information in the first 25ms of the stop as adult listeners had no difficulty in identifying the place of articulation while listening to computer edited 15-, 25-, 40-, and 135-, ms samples of the stop initial words. The researchers concluded that the Blumstein-Stevens templates do not appear to be adequate for categorising stops produced in spontaneous discourse by children at an early stage of language development. Walley and Carell(1983) conducted perceptual experiments to identify the relative importance of onset spectrum and formant transition as acoustic cues for place of articulation in stops. They developed 18 synthetic CV stimuli of which six were control stimuli and 12 conflicting cue stimuli. The control stimuli were modeled after the best exemplars of each place of articulation category from Stevens and Blumstein's (1978) transition only /ba-da-ga/ and /bu-du-gu/ continuum. The conflicting cue stimuli were synthesised by varying the shape of the onset spectra so that it resembled a different place of articulation cue from the transitions. For example, the onset spectrum shape resembled labials while transitions were for alveolars. Both normal young adults and five year old normal children participated in listening experiments where the subjects had to listen and categorise the randomly presented control and conflicting stimuli into different place categories. Group data for adults indicated that they were primarily relying on formant transition information for identifying place of articulation in the conflicting cue stimuli. Analysis of individual subjects revealed that although the majority of the adult subjects used transition information for categorising the conflicting stimuli, there were some adults who consistently utilised onset spectra for categorisation. The researchers concluded that for adult listeners neither of the cues is primary but adult listeners adopted their own strategies with the majority using formant based information for identifying place of articulation. There was a single exception amongst the conflicting stimuli, where the formant frequency cued alveolar place and the onset spectrum cued velar. Analysis of responses to this stimuli indicated that the subjects' categorisation was based on onset spectrum information. Similar findings were reported for the five year old subjects where their response appeared to be based on formant transition patterns. Once again the same stimuli proved exceptional as responses appearing to favour onset spectras perceptually salient.

Developmental differences in identifying and discriminating synthesised CV syllables that varied in the place of articulation feature /ba,da,ga/ has been reported by other researchers (Elliott, Longinotti, Meyer, Raz, & Zucker, 1981). Elliott et al(1981) concluded that 6 year old and 10 year old children had greater difficulty in labeling the /da-ga/ continuum than adult listeners. Generally it was observed that 10 year olds were more like adults in their performance than 6 year olds. The poor performance by younger children was attributed to the possibility that they may require more acoustic information than adults to identify speech stimuli (Elliott Connors, Killi, Levin &

Katz, 1979; Elliott et al.1981). Another possible explanation cited was the evidence that children are less skilled than adults in discriminating frequency transitions (Eguchi, 1976).

It appears, then, that children demonstrate a preference for formant transition cues for categorising stop consonants in terms of place of articulation. However, the exact nature of the acoustic cues for place of articulation and its realisation in the repertoire of normal children is not clear.

2.2 B) Acoustic analysis application to speech of "functional misarticulators":-

It is well known that the human ear is able to assign a common phonetic identity to acoustic stimuli which are physically different. For example, vowel normalisation enables the listener to identify as "the same" vowels produced by the small vocal tracts of children and those produced by larger vocal tract of adults. The phenomenon of categorical perception is known to interfere with traditional auditory analysis of unfamiliar languages and disordered speech (Weismer, 1984). The need for supplementing auditory analysis of disordered speech with acoustic analysis is well established (Fourcin, 1978; Weismer,1984). There has been a spurt in studies undertaking acoustic analysis of misarticulation in child speech, both developmental and functional in the late 1970s and 1980s.

Generally acoustic analysis indicates that there are systematic differences between the replacing sound and the phoneme which closely resembles perceptually the replacing sound, for example [w] in `rake' and /w/ in `wake' (Kornfeld, 1971). Kornfeld (1971) spectrographically analysed cluster and non cluster words spoken in spontaneous speech by thirteen normal children between the ages of one and two and a half years. All subjects simplified adult clusters, that is CCVC to CVC. However spectrographic differences were observed for the residual singleton of the cluster and a singleton consonant produced in words with the same vowel environment. For example,in error /bu:/ for `blue' and correct /bu:/ for `boo'. Trained listeners did not always perceive these acoustic distinctions. Similar acoustic differences were reported for clusters with approximants, for example `glass', `grass', and strident segment clusters, for example `ski', `stop'. These evidence were considered to support the hypothesis that the child may perceive speech in a different way from adults and hence may mark his production according to his perception.. The longitudinal spectrographic changes in /s/+stop cluster simplification in normally developing children observed by Catts and Kamhi (1984) did not support Kornfeld's findings. In adult speech /s/+stop clusters are classified most often as voiceless stops with long lag VOTs of more than 30ms (Davidsen-Neilsen, 1969; Catts & Kamhi,1984). Catts and Kamhi (1984) measured the VOTs of singleton stops and /s/+stop clusters produced by six normally developing children (age range 1;9 to 2;10 years) at regular intervals from 5 to 17 months. Thus their age at end of measurement ranged from 2;4 to 3;4 years. Most of the subjects were observed to realise their clusters as stops with short lag VOTs (VOTs of 0-20 ms for bilabials and alveolars and 0-40ms for velars) while some subjects realised these with short-lag and pre-voiced VOTs (VOTs of< 0ms). Since a similar distribution of VOT was observed in their singleton stops the researchers suggested that it may be concluded that these children were not maintaining acoustic contrasts between their singleton stops and cluster reduced stops. Similar observations have been made for final /-ts/ cluster words in 6 and 7 year old misarticulating children. Raaymaker and Crul (1988) reported as part of their larger study that no silence gap for the plosive element of the cluster could be acoustically detected which confirmed the phonetic transcription of these clusters as singletons.

However, in the case of singleton /r/ misarticulation, Hoffman, Stager, & Daniloff, (1983) observed significant differences in the second formant onset values between [r] error productions and correct [w] productions of 6;6 to 8;4 year old children with misarticulation . The discrepancies in the findings of researchers analysing stop-fricative reduction error (Catts & Kamhi, 1984; Raaymaker & Crul, 1988) and those analysing approximant cluster (Kornfeld,1971, Hoffman et al,1983) may be attributed to the nature of the phoneme being misarticulated. Two different possibilities may explain the observed acoustic differences between the error sound ([w] for /r/ in rake) and replacing sound (/w/ in wake) by some of the researchers. They are as follows :-

1. The child attempts to produce as close a match as possible to adult targets and hence inadvertently makes some acoustic differences between the two sounds. These differences are neither perceived by the adult nor child listener.

2. All the acoustic cues in the adult production are not available to the child due to perceptual differences. Hence the child attempts to maximise the acoustic feature in his own production, which the child perceives as important for making a contrast between the two minimal pairs, for example, rake/wake or drum/dumb.

Although Kornfeld (1971) strongly advocates the second of these explanations, in the absence of perceptual assessment to supplement acoustic data in his study it becomes difficult to make deductions about the child's speech perceptual capabilities.

2.3 C) Speech sound perception by children with functional misarticulation:-

It is largely agreed that under normal circumstances adult listeners perceive phoneme contrasts only if they produce them in their native language. However, the speech perceptual skills of the misarticulating child in relation to his productive skills is less well understood. Subtle acoustic differences in the error production are usually ignored by adult listeners and the child is thought to neutralise contrast. Difficulties in perceiving allophonic differences between error sounds may be expected on the basis of categorical perception studies in adults. However, recent investigation of phonemic perception in misarticulating children indicate that there may be a subpopulation of misarticulating children who are auditorily sensitive to allophonic differences in their error productions (Hoffman et al, 1983; Strange & Broen, 1980; Broen, Strange, Doyle, Heller, 1983; Ohde & Sharf, 1988; Rvachew & Jamieson,1989; Raaymaker & Crul.1988).

In order to make valid inferences regarding speech perceptual skills of misarticulators it becomes imperative to distinguish between various aspects of speech sound perception. Speech sound discrimination may involve peripheral perceptual mechanism while identification would involve classification of speech sounds into the categories of phonology. Thus, phonemic perception which deals with classification of speech into minimal units that signify meaning differences, would be more relevant in establishing perception-production relationship in functional misarticulators (Barton,1980).

In a comparative assessment of commonly used tests of speech sound discrimination it was observed that none of the tests gave comparable measures and the results raised serious doubts as to the validity of these tests (Bountress & Ladeberg, 1981; Bountress,1984; Locke,1980a,b). Administration of the Wepman Auditory Discrimination Test and Goldman-Fristoe-Woodcock Test of Auditory Discrimination to twenty-two 5 year old normal children indicated that the tests were not comparable. Further more, the failure of 12 of these normal children to meet the `pass' criterion of the tests raises the serious issue whether either of these tests adequately measure speech sound discrimination skills (Bountress & Ladeberg,1981). Extension of the above mentioned study was conducted by Bountress (1984). Fifty normal children in the age range 5 to 6 years served as subjects. As in the previous studies the performance of the subjects on the Boston University Speech Sound Discrimination Test, the Wepman Auditory Discrimination test and Goldman-Fristoe-Woodcock test of Auditory Discrimination were not comparable. Furthermore, the tests identified discrimination difficulty in subjects who had no obvious articulation, language, reading and learning problems, which raises serious doubts about the validity of these tests. Locke (1980a) critically examined the nature of the speech sound perception test requirement for ascertaining its importance in speech production. He also specified a set of test criteria for assessing perception in relation to production difficulties.

"The criteria are that the assessment must :-

1. examine the perception of replaced sounds in relation to replacing sounds, that is the target phoneme vs. its substitution phoneme, or, as in the case of complete omission, silence;
2. observe the same phonemes in identical phonetic environments in production and perception;
3. permit a comparison of the child's performance on target and perceptually similar control sound;
4. be based on a comparison of an adult surface form and the child's own internal representation;
5. present repeated opportunities for the child to reveal his perceptual decisions;
6. prevent non-perceptual errors from masquerading as perceptual errors;
7. require a response easily within a young child's conceptual capabilities and repertoire of responses; and
8. allows a determination of the direction of mispercep tion."

Locke(1980b, pp 445)

On application of these criteria to conventional tests, Locke (1980a) observed that most tests did not meet the eight criteria. Regarding the two response paradigms employed by these tests, that is, discrimination (AX) and identification (ABX, 4IAX), it was observed that the identification paradigm has greater potential in assessing speech perceptual skills related to production skills. Furthermore, Locke(1980b) described clinically novel procedures for assessing speech sound perception, which meet most of his 8 criteria. The suggested paradigms were classified to reflect two types of perceptual processing, Type I and Type II :

Type I: Here the paradigm mainly forces the child to compare the adult surface form with the child's internal representations and decide whether they are the same. The paradigms which fit this category are a picture identification task and a task referred to as the Speech Production-Perception Task (SP-ST). In the SP-ST task, the child is presented with the picture of the adult target word which is misarticulated by the child. The child was asked to respond yes/no to a series of questions as to the name of the item in the picture. The question structure was "Is this______?" The words placed in the blank in the carrier phrase was either the target word (SP) (For example `cap'), the incorrect production substituted for the target word (RP) (For example`tap') or a perceptually close control word (CP)(For example`lap'). One presumption that is made in this paradigm is that the examiner is capable of producing sounds that closely resemble the child's error, which may not be true. Administration of the SP-ST to 131 misarticulating subjects in the age range 3.1 to 9 years misarticulations indicated that misperceptions.occurred more often for certain contrasts than for others, with /f-θ/ confusions more than /w-r/ confusions. Generally, this paradigm appears to resemble the questions asked to the child while establishing the presence of the

'Fis' phenomenon.

Type II: The paradigm classified under Type II tests were ABX, Oddity task, and 4IAX. Inter task comparison indicated that their performance was comparable (Locke, 1980b).

In the 1980s there appears to be a proliferation of research into the assessment of perceptual skills of misarticulators in relation to their speech sound production skills. Most of these studies have used the identification paradigm, for example ABX, 4IAX, with natural speech stimuli or synthetic speech stimuli. The natural speech stimuli employed by these studies were elicited from normal adult speakers, other misarticulators and/or the subjects own error production. Selection of minimal word pairs or triplets by these researchers make these stimuli suitable for acoustic analysis. The general trend of the results of these studies indicates that misarticulators have no difficulty in identifying error sounds when correctly produced by normal speakers, but their performance on self-perception tasks and synthetic stimuli tasks appears to be different from that of trained listeners (Smit & Bernthal, 1983a; Hoffman et al, 1983, Hoffman, Daniloff, Benoga, & Shuckers, 1985; Strange & Broen, 1980; Locke & Kutz, 1975).

i) <u>Perception of adult productions:-</u>

Locke(1980b) reported the phonemic perception capability of 131 children in the age range 3.1 to 9.9 years with varying error patterns. The Speech perception-production task (SP-PT) was employed for assessing perception. An overall 97% correct score for correctly produced sounds was observed. In the case of incorrectly produced sounds, about 27 to 39% of the contrasts were misperceived. However, over 67% incidence of misperception being attributed to the /f-θ/ contrast. The /w-r/ contrast was not misperceived. The high incidence of /f/-/θ/ misperception was associated with age, with better scores observed in the older group.

Smit and Bernthal(1983a) compared five year old children with misarticulations on measures of expressive receptive language and perception of word-final voicing contrasts. The experimental group was further classified as syllable reducers or as substituters depending upon their error patterns. Their results indicated that there were specific differences between the two groups. The syllable reducers made more expressive syntax errors than substituters and control group in specific aspects of expressive language, namely functor words and pronoun category. All the subjects performed extremely well on the perception task. The task employed was mainly to listen to adult production of a single word and point to a picture from four alternatives. The single words were randomised from a set containing six minimal pairs which differed in voicing of the final obstruent and three minimal triples in which initial voiced and voiceless stop singles and /s/+ stop clusters were contrasted. Significant differences in the performances of the experimental group was noticed as compared to normals while listening to minimal triples, for example, `speech, peach, beach'. However, all the three groups performed equally well while listening to minimal pairs. Error analysis of minimal pair data strongly suggested that certain stimulus pairs were intrinsically more difficult for children than other pairs. The familiarity of the word had greater effect on the perception of "difficult" word pairs than "easy" word pairs.

Similar findings have been reported by Hoffman et al (1983) who investigated perception-production relation in children with /r/ misarticulation. There were 12 children in the experimental group in the age range 6:6 to 8:4 years. Five normal speaking children in the same age group formed the control group. The stimuli used were five sentence pairs, with each pair differentiated by a single phoneme contrast /r/ and /w/. As part of a larger study the researchers ascertained the performance of the two groups in identifying correctly produced /r/ and /w/ minimal word pairs spoken by normal children. The performances of both the groups were comparable in this task with above 85% correct identification scores. Individual scores indicated that there were three subjects with misarticulation who performed 15% worse than the lowest score obtained by normal speaking children. It may be concluded from the above studies that phonemic perception for correctly produced stimuli is by and large intact. Although there is general agreement with regard to perception of adult surface forms, similar agreement of results is not observed in the identification of self produced error sounds.

ii) <u>Self-perception:</u>-

Wolfe and Irwin (1973) studied the ability of children who consistently misarticulated /r/, to judge the correctness of /r/ productions. Their subjects were more proficient in comparing their live productions with recorded model utterances than they were in judging recorded samples of their own speech. Similar results were observed as part of a study investigating the effect of communication disorders on memory by Locke and Kutz (1975) Thirty kindergartners(mean age 5.7 years) with /r/-misarticulation were the experimental groups. Fifteen children who correctly produced /r/ and /w/ matched for age and sex to the experimental group formed the control group. Both the groups were observed to have perfect perception of adult production of the two phonemes. The test stimuli consisted of minimal word triplets that is \`ring, wing, king' and \`shack, sack, tack'. The children were required to point to each picture of the stimulus as s/he heard self-produced stimulus words through a tape recorder. The control group made less than 1% error while listening to their own correct productions. The experimental group's high tendency towards pointing to the `wing' picture in response to an equal number of test stimuli appeared to indicate that they did not perceive contrasts in their own productions. The investigators argued that these results cast strong doubts on the long held belief that children perceive contrasts in their error productions which are heard as homophones by adults.

In an attempt to observe the /s/-misarticulator's skill in identification of his error production, Wilcox and Stephens (1982) conducted a perceptual experiment. Six misarticulators with different types of /s/ errors, for example dental, retracted, and lateral and two normal speaking children participated in the study. All the children were required to listen to 15 short phrases containing /s/ in a variety of phonetic contexts and judge whether the /s/ sound was "normal" or "defective". Overall, the performance of the misarticulators in self-labelling was comparable to that of the other listeners' performance on the some items. Speakers with dental and lateral production were better at identifying their own speech errors than others. However, the paradigm used i.e. "normal" or "defective" involves different type of judgment than those usually required during communication interactions. Contrary findings have been reported by Hoffman et at (1983) who assessed the self-perception skills of 12 /r/- misarticulating children aged between 6;6 to 8;4 years, to identify their own production of /r/ and /w/ initial words. The results indicated that these children were confused by the error productions and they assigned nearly 50% to each phoneme category. This guessing strategy did not extend to the misarticulating children's production of /w/ initial words. The control group of five normal speaking children who also participated in identifying /r/ and /w/ initial words spoken by the misarticulating children performed significantly lower than the 50% chance level in identifying the /r/ initial words. The general trend appeared to favour categorisation of /r/ initial words as /w/ initial words by the control group. Thus the data suggested that children who misarticulate differ from children who do not misarticulate only in their perception of /r/ error productions.

Another experiment, employed similar analytical procedures to, the identification scores of normal adult and misarticulating children while listening to word initial /w,r,l,j/ words produced by misarticulating children. Results indicated that the misarticulators and their parents used different listening strategies from trained listeners (Chaney, 1988). Two groups of 4 children in the age range 4.0 to 7.5 years were included in experimental (child) group. The developmental group (DG) included normal preschoolers (mean age 4;4 years) with intelligible speech and misarticulations restricted to [w] or [j] substitution for singleton /r/ and /l/; and [w] substitutes or semivowel omissions in /r/ and /l/ clusters in all contexts. The other experimental group, consisted of articulation impaired group (AIG) with a mean age of 6;8years. Their speech was characterised by /r/ and /l/ singleton misarticulation by two of the children with the other two having only /r/ singleton misarticulation. All four children in this group substituted [w] for /r/- and /l/- clusters in all contexts. A group of normal speaking children with a mean age of 4;4 years were included in the control group (CG). The stimuli and material consisted of eight sets of minimal contrastive,/w,r,l,j/ word initial singleton and clusters. All the three groups participated in a task where the child produced each of the 32 stimulus words in the phrase," That's a__________". The recorded phrases formed the stimuli for the identification task. Examples of each stimulus word spoken by adults in the carrier phrase were also recorded and randomised with the child productions. Three experimental groups, their parents and adult trained listeners participated in the listening task. The results indicated that all the children were accurate in the identification of adult produced semivowels, which corroborates with findings of previous studies mentioned earlier. However, they performed differently in identifying self-produced semi-vowels. Both the experimental groups demonstrated the ability to identify self-produced apparent homophones. Although the parents of the misarticulators felt confident in understanding their child's speech, their identification score revealed that they performed well below chance. However they differed from trained listeners in that they selected /w/,/r/ and /l/ responses equally. The trained listeners demonstrated a strong preference to select a /w/ response while identifying /r/ and /l/ initial stimulus words produced by misarticulators. Thus this study by Chaney (1988) strongly support the findings of Hoffman et al (1983). Inclusion of acoustic analysis of production errors by these two studies lent support to the claim that some children who misarticulate semi-vowels are sensitive to allophonic differences which adults ignore. The children's ability to perceive contrasts in their own error production of the stimulus word was strongly related to second formant frequency transition rate differences (Hoffman et al, 1983, Chaney, 1988). Considering the subtle perceptual differences observed in some of the functional misarticulators as compared to normal children and adult, it was suggested that refined perceptual testing utilising synthetic speech stimuli for identifying "categorical boundaries" for error sounds may be relevant in identifying the nature of the misarticulating child's perceptual deficits.

iii) <u>Perception of synthetic speech stimuli continuum by "functional misarticulators":-</u>

Synthetic speech stimuli varying along a continuum for one or more specified acoustic feature have proved to be useful in ascertaining the acoustic cues which contribute towards the perception of specific speech sound category. Formant synthesisers are commonly used in speech perception research, where various formant frequency, transition, aperiodic energy, pitch contours are specified and generated. The observation that some /r/-misarticulators are auditorily sensitive to allophonic differences in their contrast production raise the issue whether they have poorly formed perceptual phonemic boundaries for relevant acoustic cues (Hoffman et al, 1983; Chaney, 1988). Broen, et al (1983) studied the skills of two groups of 3 year olds in the identification of approximant initial words. The children included in the normally developing group, produced /w/ correctly. 75% of the subjects correctly produced /l/ and 37.5% correctly produced /r/. Generally for those misarticulating either /r/ or /l/ substituted /w/ or `w' like sounds. The other group consisted of articulation delayed children with all of them misarticulating /r/. The trend for these children was to neutralise /w/-/r/ contrasts with 50% subjects further neutralising /w/-/l/ contrasts and the /r/-/l/ contrasts. The stimuli for perception assessment were synthetically generated tokens of the minimal word pair approximants i.e. wake-rake, rake-lake; wake-lake and a control set of minimal pair approximant bilabial-plosive (bake-rake, bake-wake....) contrast. In general, the children performed extremely well on the perceptual task with an average error of 3/120 by normal group and 12/120 for the delayed group. A closer inspection of the scores revealed that mean scores did not indicate the real difference between the normally developing children and the delayed articulation group. The main difference between the two groups was the relatively large variance for the misarticulating group. Children in the misarticulating group were more variable in the perception task which involved that contrast which they neutralised in their production; variability was less in those for which they maintained contrasts. The researchers concluded that specific perceptual difficulties accompany some but not all articulatory problems. The findings of Broen et al (1983) indicated that synthetic speech stimuli were useful in detecting perceptual deficits for the error sounds. However, as they did not use synthetic stimuli varying along any specific acoustic continuum it is difficult to ascertain whether the perceptual deficits were due to poorly defined categorical contrasts or to other factors.

Hoffman et al (1985) observed that /r/-misarticulating children in the age range 6;0 to 6;11 years performed differently from normal speaking children while identifying synthesised /r/-/w/ initial minimal word pairs, varying along the acoustic continuum from /r/ to /w/. "Average identification performance for a range of synthetic stimuli indicated less discrete categorisation by misarticulating children compared to their normally articulating peers" (Hoffman et al, 1985, pp. 51). Ohde and Sharf

(1988) conducted a similar experiment to that of Hoffman et al (1985). Besides using synthesised stimuli along the /r/-/w/ continuum, they included synthesised stimuli varying along the /b/-/w/ continuum in minimal pairs, as these sounds were correctly produced by both experimental and control group. Their results confirmed that /r/ misarticulators have less well defined categorical boundaries for the /r/-/w/ continuum than do normally articulating children and adult listeners. The performance of misarticulating children, normal children and adult listeners on the /b/-/w/ continuum indicated that the poor categorical boundaries observed in the /r/-/w/ continuum did not extend to the /b/-/w/ continuum. Thus, the perception deficit observed for the misarticulating group was not global in nature (Ohde & Sharf, 1988). Such specific perceptual deficits in /ts/ final cluster misarticulators has been observed by Raaymaker and Crul (1988). These subjects demonstrated significantly different categorical boundaries while listening to a stimulus series consisting of speech continuum from /maes/ to /maets/. The silent period was varied by 10ms steps to make the stimulus continuum. Similar findings have been observed for /ʃ/ and /θ/ misarticulators for the continuum /s/ to /ʃ/ and /s/ to /θ/. (Rvachew & Jamieson, 1989). Thus, there appears to be strong evidence to support the claim that a specific problem in speech production may be accompanied by a specific perceptual deficit. Acoustic analysis of a limited number of correctly articulated /maets/ by the misarticulating groups indicated that they maintained a longer silence (mean 114.1 ms) than adults, normal speaking children and than those misarticulators who had errors other than /ts/ clusters. This was surprising as the /ts/ misarticulators demonstrated the shortest mean silence periods for procuring the /maets/ Vs. /maes/ distinction as compared to the other groups. This lack of correspondence between production and perception lead the researchers to conclude that the misarticulators had a broad and imprecisely defined representation of the contrast as a whole (Raaymaker & Crul, 1988).

Thus, perception tasks involving listening to adult productions, self-productions and synthetic speech stimuli appear to be useful in defining the exact nature of perceptual deficits in children. Of these, self-production stimuli and synthetic speech stimuli appear to be more useful than adult productions in identifying perceptual deficits. Furthermore, inclusion of acoustically analysed data in perceptual studies appear to be essential.

2.4D) Perception-production relationship in children with velar fronting:-

Very little research has been done which includes both perceptual and acoustic aspects of velar misarticulation. In a comprehensive review of acoustic analysis application to misarticulated speech, Weismer (1984) rightly emphasises the lack of acoustic data related to errors in velar articulation. However, Weismer contends that " acoustic analysis would not contribute much to a better understanding of velar fronting .... because the t/k and d/g errors, which are the output of velar fronting, seem to be highly accessible perceptually and therefore handled adequately by an auditory-based phonological analysis" (pp. 47). This may not be true. English has only three contrastive (phonemic) places of articulation, however phonetically the number of places are much greater. Most Indo-aryan languages have four contrastive (phonemic) places of articulation for stops, namely, bilabials, dental, retroflex and velar. In an apparent neutralisation the English velar fronter may be using allophones, for example dental/alveolar which may not easily be available perceptually to adult English listeners, this being especially true for the alveolar/retroflex distinction. Studies including acoustic analysis of application alone to velar fronting largely indicates greater variability in target /k/ production and in some subjects acoustic distinctions between the targeted /k/ and the appropriate /t/. Forrest, Weismer, Hodge, Elbert and Dinnsen (1990) reported the results of statistical analysis of /k/ and /t/ produced by four normal and four children with phonological disorders whose error patterns included velar fronting. Based on the FFT of the first 40ms of the VOT, they derived first four spectral moments (mean, variance, skewness and kurtosis) of the output from the two groups of children. One of the subjects with phonological disorder (K.R.), was observed to produce target minimal pairs which could be distinguished based on the kurtosis and skewness. They observed that this distinction was not the same as those obtained for the normal group for their /k/~/t/ productions. Greater variability in target /k/ was reported. Interestingly, even after spontaneous acquisition of perceptually acceptable by the /k/~/t/, the acoustic measures were different from those of children with no production errors. Furthermore, with the emergence of /k/, K.R.'s target /t/ phonemes appeared to be less stable.

Recently, Forrest, Weismer, Elbert and Dinnsen (1994), reported their findings of FFT based derivation of the first four spectral moments (mean, variance, skewness and kurtosis) of velar and alveolar initial words spoken by velar fronting children with different degrees of knowledge of the target contrast. That is, one group of phonologically disordered subjects who had a variety of phoneme errors but produced perceptually acceptable /k/~/t/ and the other group who produced acceptable /k/~/t/ in word initial position. The results of the acoustic analysis indicated that both the groups produced target appropriate /k/ and /t/ differently from the group which had no production errors. Acoustic measures distinguished the two groups mainly in terms of degree of variability, with the group with least knowledge of the contrast having greatest variability.

However, lack of perception test in the above studies makes it difficult to ascertain whether the acoustic differences in targeted /k/ and appropriate /t/ reflects disordered perceptual process or inadequate production knowledge alone. Furthermore, since the acoustic analysis was restricted to the first 40ms of the VOT it is not clear whether individuals with fronting of velars maintain acoustic differences in features other than those important in normal production. In other words the acoustic analysis conducted in these two studies provides very little information on the nature of production dynamics in fronted velars.

Hewlett (1988) investigated the acoustic phonetic characteristics of velar errors in a 5.1 year old phonologically disordered child. The child named pictures of a list of eight /k/ and /t/ initial minimal word pairs, of which only voiceless cognates were acoustically analysed, that is, /ki/, /kaep/, /taep/. The acoustic parameters investigated were VOT of initial plosive and characteristics of the onset spectra, such as the frequency of highest spectral peak above 2kHz and shape of the spectrum. The method used for deriving the onset burst spectrum was slightly different from Stevens and Blumstein's (1978) procedure. The Sonograph (Kay Elemetrics 7800) was used for this purpose with frequency range 0-8 kHz. "With this instrument the frequency bandwidth determines the time span of the signal analysed. A 150 Hz. bandwidth was chosen, giving a time span of 6ms, which was located somewhere between 10 ms and 25 ms after the onset of the consonant release. In a few cases where the onset of release appeared to be weak or where there were repeated bursts, the spectrum was made from a point slightly further on. The hi-shape function was used giving a high frequency pre-emphasis of 6dB/octave above 1 kHz."(pp. 33). Results of acoustic analysis indicated that the VOT values for velar and alveolar production were not significantly different for either the control adults or for the children or for the misarticulating child. The highest spectral peak above 2 kHz was found to be significantly higher in frequency for alveolars as compared to velars with greater difference for adult than normal children. However, no significant difference was observed in this acoustic measurement for the initial plosives produced by the misarticulating child. Further acoustic measurements were done for the "new" velars learnt by the misarticulating child after receiving speech-language therapy. Surprisingly no significant differences were observed for the highest spectral peak above 2kHz. Furthermore, as the Blumstein-Stevens templates for alveolars did not distinguish the onset burst spectra, Hewlett (1988) devised templates to distinguish spectra of /k/ and/t/ produced by adults. "The upper frequency end (arrowed) is placed upon the highest spectral peak above 4kHz, while the base line of the template is held parallel with the x-axis of the spectrum. For /t/ no peak should protrude above the template line, whereas for /k/ some part of the spectrum should do so." (pp. 35).

The success rate of the templates in distinguishing /t/-/k/ spectra in adult production was 95%, in normal speaking children it was 69.5% and in velar misarticulators' error production it was 59%. After the child learnt the velar sound, the template was less successful in distinguishing /k/-/t/ spectra with a poor success rate of 37%. The reason for this may be that the main acoustic distinction between /k/ and /t/ in this child was in the trajectories of the formant transitions. With the aim of gaining some information as to the nature of the auditory cues present in the disordered child's newly acquired velar sounds, perceptual experiments were conducted by the investigator.

In the perceptual experiment, one example each of \`key', \`cap', \`tea' and \`tap' correctly spoken by the phonologically disordered child and an adult speaker was used to determine the stimulus type for the two perceptual experiments conducted by Hewlett(1988). In the first experiment, correct production of the phonologically disordered child was presented to 19 trained listeners. Their identification score was 89% correct.

In the second experiment, words spoken by normal speakers was spliced. The segments were (1) the entire word, (2) 60ms of consonant retained with vowel removed and (3) the spliced word with 60 ms of the consonant removed. The scores indicated that the highest score was for the first 60 ms of the initial consonant release. Specific differences were observed while listening to spliced adult and the phonologically disordered child's correct productions. Surprisingly, the best scores for adult stimuli was for the first 60 ms of the initial consonant release, and the poorest identification scores were for the entire word. While listening to newly learnt alveolar/velar contrast, the listeners had best identification scores for the initial 60ms excised words. Thus, consonant information in newly acquired velars appear to be more in the vowel region. However, lack of information as to whether the first 60ms contained burst only or parts of transition also makes it difficult to decide their relative importance.

Young and Gilbert (1988) reported the results of a study which looked at whether VOT differences exist for normal speakers and in children who exhibit velar fronting in their speech. They also attempted to ascertain if these children could differentiate their own production of adult target words. A naming task and spectrographic measurement was used. Results showed no differences in velars and alveolars for VOT measures in the case of fronters. This was in contrast with the values found in normal children where a number of minimal pairs had significant differences in VOTs for alveolars and velar stops. On comparison of VOTs across groups, significantly longer VOTs were found mainly in voiceless stops for the experimental group. The longer durations was taken to reflect immaturity of the speech production system, as evidence from normal speech indicates that younger children produce longer speech sound features.

Furthermore, the investigators reported the performance of both groups in a perception task where the subjects had to identify stimulus words spoken by themselves earlier. In the identification task, normal children scored 83% correct identification. The mean correct identification score for velar fronters was 53%. However, one of the children in the experimental group achieved 83% correct identification which indicates that this child was able to perceive differences in his production of error sounds, which adults perceived as homophones. The researchers stated that their findings suggest that "velar fronters in this investigation should not be identified as functional misarticulators but as children whose entire phonological systems were delayed." (pp.246).

Since Young and Gilbert (1988) looked only at VOTs it is difficult to ascertain whether differences would be present in acoustic cues directly related to place of articulation information,for example formant transitions and onset burst spectra. Furthermore, the only feature of an immature system observed was the longer VOTs in velar fronting children. The lack of inclusion of words which were not misarticulated makes it difficult to ascertain whether the children's poor performance in the perceptual task was due to a failure to understand the task or a real perceptual difficulty. The lack of evidence to support whether perception of velars was also immature makes it difficult to attribute the observed misarticulation as being due to a delay.

This review of literature reveals a paucity of research on the perception-production relationship in velar error production. The limited studies on acoustic characteristics of fronting of velars and their self-perception of velar errors indicate that a sub-population of velar misarticulating children may be sensitive to allophonic differences which are perceived as homophones by adults.

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3 Chapter III: METHODOLOGY

The key issues addressed by this study are whether Hindi or Marati speaking children who front their velars

(1) maintain critical acoustic differences between their velar errors and dental sounds, and

(2) are auditorily sensitive to replacing sound and dental sounds which have critical acoustic differences.

Although the perception and production components of the experimental tasks were conducted on the same set of subjects, for the sake of clarity and convenience the two aspects will be treated as separate experiments, that is,

Experiment I: investigates acoustic and perceptual difference in /k^h/ and /$\underline{t}^h$/ production by individuals with and without velar fronting(chapter IV) and,

Experiment II: investigates speech sound perception in velar fronting children (chapter V).

It must be stressed that although these are being reported as two experiments in sequence, the data collection did not necessarily follow the same sequence. On the contrary the perception task and the production task were conducted almost simultaneously on the same experimental group. Such an approach facilitates the study of the "perception-production" relationship in velar fronting children which is the focus of this thesis. Hence, in chapter V, the discussion of Experiment II includes the discussion on the relation between production and perception in velar fronting.

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4 Chapter IV: EXPERIMENT I

Experiment I: Acoustic and perceptual difference in /k^h/ and /$\underline{t}^h$/ attempted by normal and velar fronting children.

4.1 Introduction

Recognizing the fallibility of the human ear in transcribing unfamiliar languages and disordered speech, several investigators have included more objective techniques in their study of speech production. By supplementing perceptual analysis with acoustic analysis several researchers have demonstrated that children with phonological disorder often maintain significant acoustic differences between the replacing sound and the phoneme which perceptually resembles the replacing sound (Weismer, 1984).

From the review of literature it is apparent that very few investigators have applied acoustic analysis techniques to velar fronting. The paucity of studies appear to be due to two reasons, that is

a) the assumption that t/k and d/g errors are highly accessible to perceptual analysis, and

b) the controversy as to the perceptual cues to place of articulation and the difficulty in formant tracking in child speech.

However, the few studies which have applied acoustic analysis techniques to velar fronting indicate that the first of the above assumption may not be true (Hewlett, 1988, Young

& Gilbert, 1988. Forrest et al, 1990). Hence, the present experiment mainly attempts to answer the following questions

1)Do children with velar fronting consistently substitute a dental plosive for the target velar sound?

2)Do children who front velars in their production make acoustic differences in their velar error productions and replacing lingual stop consonant?

3) Are there acoustic differences between word initial velar and lingual stop contrasts attempted by children fronting their velars, and children with no production errors?

Analysis of speech output of children with velar fronting needed to address issues both in perceptual and acoustic analysis:-

Issues in perceptual analysis of abnormal speech:-

From the review of literature (Chapter I page 34-37 and Chapter II) it is apparent that a number of factors influence articulatory phonetic analysis, such as, listener's language background, and training. In India, formally trained phonetic transcription experts are not easily available. The present investigator initially transcribed the data. Considering experimenter bias, the present investigator requested a very experienced speech scientist to transcribe the data. Furthermore, three more experienced listeners were requested to participate in a listening experiment. Hence, perceptual analysis was undertaken as an experimental task in order to ensure fairly valid transcription.

Issues in acoustic analysis of velars and dentals:-

Considering the problems in formant tracking in children's high pitched production (Huggins, 1980), the Stevens-Blumstein approach appears to be more suitable for analyzing velar fronting than F2 transition measures in child speech. However, there appears to be some doubt as to the usefulness of this acoustic measurement procedure in differentiating velars and alveolars produced by children. Chapin, Tseng, and Liberman, (1982) concluded that the Stevens-Blumstein templates do not appear to be adequate for categorizing English stops produced in spontaneous discourse by children at an early stage of language development. In their study the spontaneous productions of two children in the age range of 71 to 75 weeks were analyzed. At this age a child's production is largely holophrastic in nature where the productions are extremely immature. In experiment I, it was felt necessary to conduct a pilot study in order to ascertain whether the Stevens-Blumstein templates are adequate for categorizing children's production at a more mature stage of phonological and articulatory development.

Compared with alveolar plosives, dental plosives have a smaller cavity anterior to the release. Acoustically this should result in a higher burst `locus' and a more rapid F2 falling transition when the following vowel is [a]. Hence it was speculated that the dental average Linear Predictive Coefficient (LPC) spectrum would also show increased energy in the higher frequency and would broadly match the characteristics described by Stevens and Blumstein (1978) as "diffuse-rising". It was speculated that the alveolar template would be robust for categorizing average LPC spectra of the initial 26 ms of dental aspirated voiceless plosives, the major production difference between alveolar and dental plosives being the place of articulation. Although Lahiri et al (1984) observed that average LPC spectra of dentals produced by French and Malayalam adults did not have the diffuse-rising shape, it is not certain whether the dentals produced by Hindi and Marati children have this shape. The pilot study attempts specifically to answer the question "Do the Velar and Alveolar templates proposed by Stevens and Blumstein (1978) differentiate average LPC spectra of initial velar and dental aspirated voiceless plosives spoken by Hindi and Marati speaking children with no output errors?"

4.2 **Pilot study :-**

4.2.1 **Procedure:-**

i. **Subjects:-** Five children were included in this study (2 girls and 3 boys in the age group 5;2 years to 5;8 years with a mean age of 5;5 years). They will henceforth be referred to as control group I. The subjects will be re-ferred to as CSs1, CSs2, CSs3, CSs4 and CSs5. These child-ren were randomly selected from ten subjects (7 boys, 2 girls with a mean age of 5.7 years, which ranged from 5;2 to 7 years) with normal speech, cognitive, language and hearing skills matched in age, sex and mother tongue to the subjects in the experimental group mentioned in the main experiment (page 105).

ii.**Speech stimuli:**- In an attempt to `neutralize' the effect of `bilingualism' as an extraneous variable, minimal pairs meaningful to both languages were selected. The following contrasts were included from the Marati and Hindi languages:-

Marati		**Hindi**	
/k^halI/	`down'	/k^halI/	`empty'
/$\underline{t}^h$alI/	`plate'	/$\underline{t}^h$alI/	`plate'
/palI/	`lizards'	/palI/	`island'
/halI/	`green worm'	/halI/	`green worm'

Line drawings representing words in the child's first language were selected for all activities for each child (Appendix IV). For example, a child with Hindi as his/her language spoken at home was shown the pictures of `empty', `island', `plate' and `strange worm'. Ten repetitions of the stimulus words were randomized to form two separate lists of 40 (4X10) words in Marati and Hindi (Appendix V).

iii. **Production task:**- The production task consisted of a picture naming task. Recordings were made of subjects speaking the 40 words in one of the lists using a monophonic cassette tape recorder. A `repeat-after-me' task was employed where the child failed to name a word in sufficient isolation. The microphone was kept eight inches in front of the mouth. All recordings were made in the clinic/school in quiet room conditions. Thus in all a total of 40 words were recorded from each subject, giving a total of 200 audio tape recorded tokens of the four stimulus words. In order to avoid fatigue the recording was conducted in two sessions, with 20 words being recorded in each session.

iv. **Acoustic analysis:**- One hundred audio recordings of /k^hali/ and/$\underline{t}^h$ali/ spoken by the five children in control group I were digitized at 16kHz with a 12 bit quantization using the Sensimetrics [1] system for acoustic analysis. Wide band spectrograms were generated with window sizes of 96 samples and a Fast Fourier Transform (FFT) interval of 1.62 ms. Averaged LPC (order 24) spectra of the initial 26 ms of the burst/aspiration were also generated . All the averaged spectra were then compared with the Blumstein-Stevens templates for velars and alveolars to ascertain whether the templates successfully categorize velars and

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1.Sensimetrics Speech Station (Version 2.1). Aeriel Corporation, 433 River road, Highland Park, New Jersey, 08904.

dentals as following the procedure specified by Stevens and Blumstein (1978) and Blumstein and Stevens, (1979) (Figure 4.1.1, 4.1.2, 4.1.3, and 4.1.4).

4.2.2 Results and Discussion:-

Two possibilities were explored:-

(1) Whether the average spectra would fit the velar template.

(2) Whether the average spectra would fit the alveolar template.

An ideal template would be equally successful in accepting the target average LPC spectra and rejecting the spurious ones. So a high correct acceptance and rejection score would indicate a better template. The results of the template matching procedure are given in table 4.1.1 for velar Template and 4.1.2 for dental Template.

Table 4.1.1:- The percentage of velar and dental LPC spectra that was accepted and rejected by the **velar template.**

Ave. LPC Spectra	Accepted	Rejected
Velar	54%	46%
Dental	26%	74%

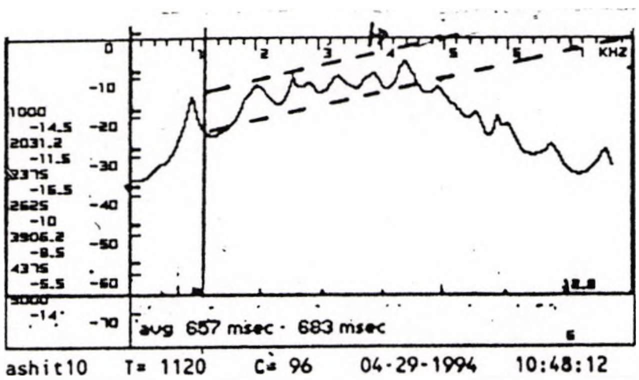


Figure 4.1.1:- The average LPC spectra of first 26ms of /$\underline{t}^h$ alI/ produced by subject in control group I accepted by the alveolar template. The dotted line indicate template.

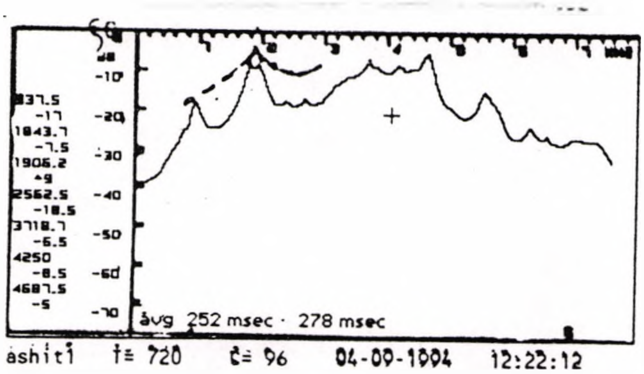


Figure 4.1.2:- The average LPC spectra of first 26ms of /$\underline{t}^h$ alI/ produced by subject in control group I accepted by the velar template. The dotted line indicate the template.

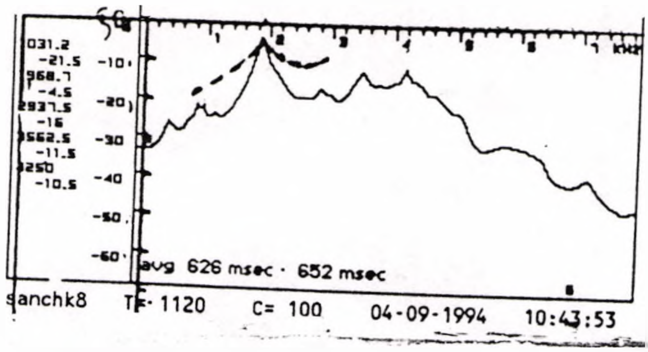


Figure 4.1.3:- The average LPC spectra of first 26ms of /k^h alI/ produced by subject in control group I accepted by the velar template. The dotted line indicate the template.

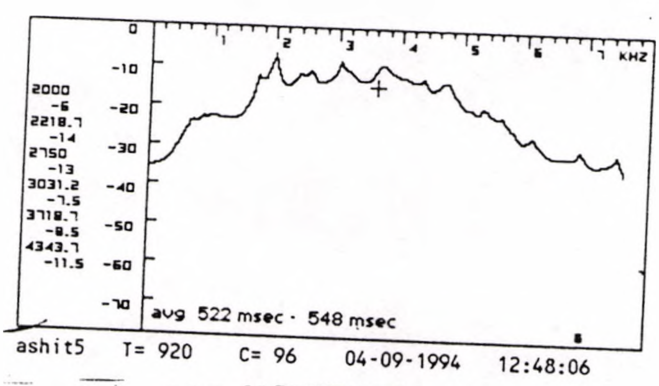


Figure 4.1.4:- The average LPC spectra of first 26ms of /$\underline{t}^h$ alI/ produced by subject in control group I rejected by both the templates.

Table 4.1.2:- The percentage of velar and dental LPC spectra that was accepted and rejected by the **alveolar template**.

Ave. LPC Spectra	Accepted	Rejected
Velar	2%	98%
Dental	62%	38%

From the two tables it appears that both the templates were poor at identifying the target consonants, with the alveolar template (62%) performing slightly better than the velar template (54%). The velar template appears to be better at rejecting dental average LPC spectra than at accepting average LPC spectra of velars. The same seems to be true for dental templates with slightly better scores.

Application of the One Sample Proportions Test on these scores yielded Z score value of -4.6, indicative that the velar template was performing at chance, while identifying velar average LPC spectra. Although the dental template score for correct identification is slightly better than that of the velar template, the resultant Z-score value of -3.8 indicates that it was identifying significantly fewer dentals than the number present in the data. Both the templates appear to be better at correct rejection than at acceptance. However, once again the Z-score value of -2.6 obtained for correct rejection by the velar template indicates that it was rejecting significantly fewer dentals than the number known to be present in the data. On the other hand, the alveolar template correctly rejected 98% of the average LPC spectra of velars. Another interesting feature observed was that 28% of the LPC average spectra were rejected by both the templates indicating that LPC spectra rejected by one template was not automatically accepted by the other. The poor performance of the templates cannot be attributed only to the use of aspirated voiceless velar and dental plosives from Hindi and Marati in this study, as the performance of the velar template appears to be similar to those reported by Chapin et al (1982) who reported 40% correct acceptance and 75% correct rejection rate for the velar template. There is no mention in their report of instances of rejection of spectra by both the velar and alveolar templates. The results are thus in agreement with those reported by Chapin et al, (1982) who observed that the velar template is not adequate for identifying velars in the productions of children. Thus it may be concluded that the velar templates seem inappropriate for identifying velars produced by children at a more mature stage of phonological acquisition than the subjects of Chapin et al, (1982). The acceptance rate for dental spectra by the alveolar template is comparable to those reported by Lahiri, Gewirth, and Blumstein (1984) in their pilot study with French and Malayalam dentals. They observed that the shape of the dental spectrum not accepted by the diffuse-rising template were predominantly diffuse and flat. This resulted in the confusion of dental with labial consonants. In the present study among the rejected dental spectra only one dental spectrum could be described as diffuse flat. Thirteen of the nineteen dental spectra rejected by the alveolar template were accepted by the velar template (Figure 4.1.2). The rest of the rejected dental spectra had a mid-frequency resonance along with the rising shape which interfered with acceptance of the spectra by the alveolar template (Figure 4.1.2 and 4.1.4). Minor adjustment to the template would not therefore have made the alveolar template more accurate. Thus the alveolar template is of limited use in identifying initial dental aspirated voiceless plosives produced by children. In general it may be concluded that the Stevens-Blumstein approach to acoustic analysis of stop consonants is of limited use in acoustically differentiating initial dental and velar aspirated voiceless plosives produced by Marati and Hindi speaking children. This leads to the conclusion that other measures need to be developed in order to accommodate research into the suppression of velars in these languages.

A detailed report of the rationale and results of a detailed acoustic analysis of /k^halI/ and /$\underline{t}^h$alI/ attempted by children with fronting of velars and those with normal production is presented in the next section. Also included is the results of perceptual analysis.

4.3 Acoustic & perceptual analysis of normal & abnormal velar and alveolar stops:

The main grounds for applying acoustic analysis techniques to children with phonological disorder is to ascertain whether the child maintains critical differences in his production instead of the contrast expected by the adult listener (Weismer, 1984). Hence measurement of those acoustic parameters known to cue phonemic difference for adult listener alone would be of limited value. It would add very little information to perceptual analysis, such as narrow transcription. Hence the present analysis attempts to ascertain acoustic differences in velar and dental plosives in a number of acoustic parameters which to some extent reflect production difference. Furthermore, perceptual analysis of data obtained from the experimental group was also undertaken with a view to ascertaining the nature of velar fronting.

Initial voiceless aspirated plosives are characterized by an initial release (Transient) followed occasionally by a `frication' and then by the aspiration which leads to periodic portion of the vowel (Fant, 1973) (Fig.4.2.1).

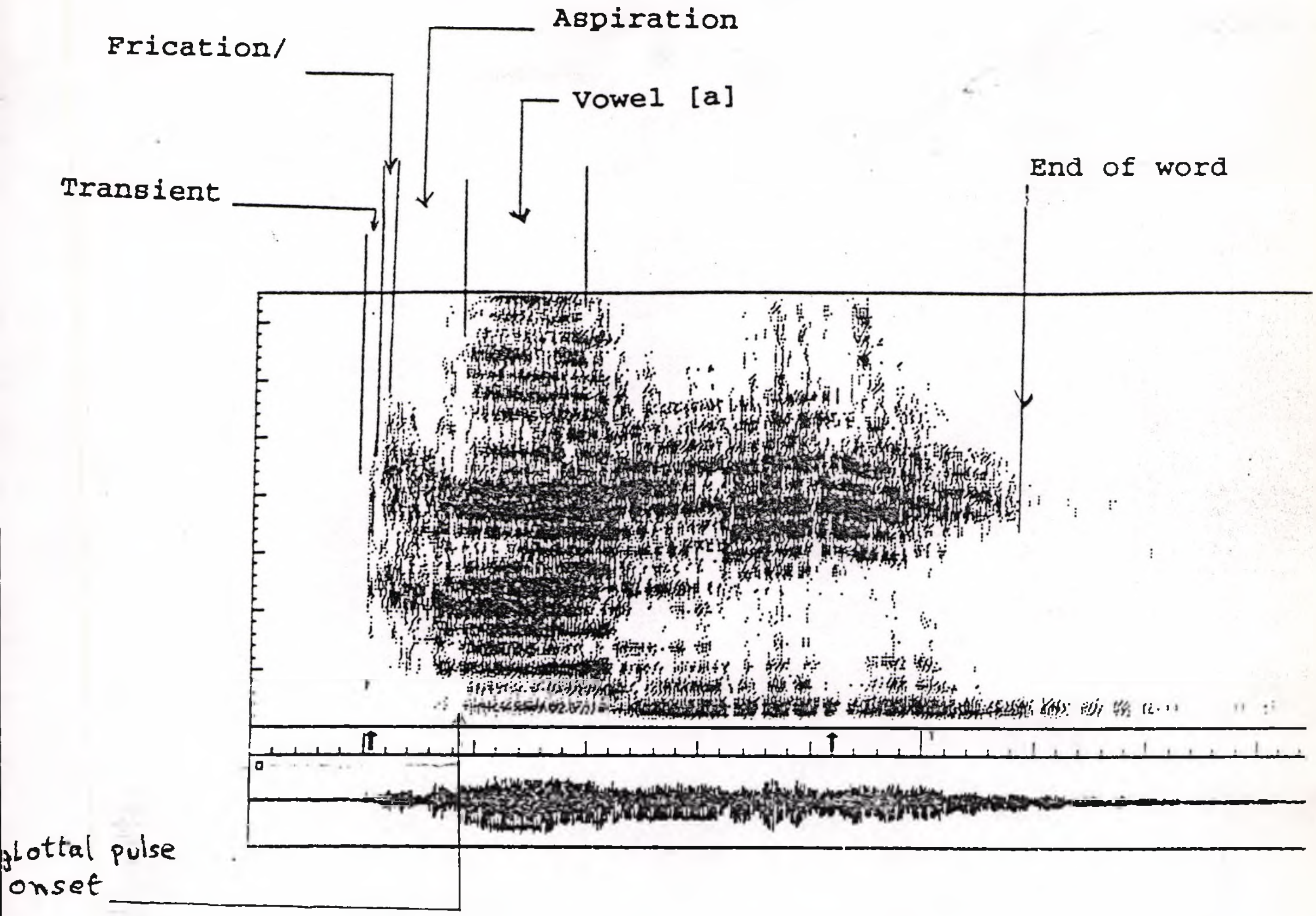


Fig. 4.2.1 :- The various segments of the word initial voiceless aspirated plosive is marked on the WB spectrogram (Sensimetrics speech station(2.1)) of /t^{h}al/ spoken by a normal speaker.

Transient analysis:-

The source filter theory of speech production predicts that both the size and nature of the cavity in front of the sound source influence its frequency characteristic. Generally it is observed that the larger the cavity in front of the sound source the lower the resonant frequency response and vise versa. In the case of plosives the sound source is aperiodic and situated at the point of articulatory closure (and subsequent release) in the vocal tract. In velars, therefore, a larger cavity is formed in front of the source relative to that for dentals. Hence for the transient portion of the velar, frequencies which are lower than those for dentals will be resonated. The predicted high frequency dominance in apical plosives has been incorporated into the alveolar template of Stevens and Blumstein (1978) and the high `loci' calculated by extrapolation of the formant frequencies (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967 & Cooper, Delattre, Liberman, Borst & Gerstmanet, 1952). Fant (1973) measured formant two (F2) in the transient segment and observed higher F2 for alveolars as compared to velars. He also obtained longer transients for velars compared to other plosives. Similar findings have been reported by Hawkins (1986a,b). Furthermore, the burst spectra of velar stops have been said to have a spectral prominence in the mid-frequency range of 800-4000 Hz (Hawkins, 1986a,b; Hawkins & Stevens, 1987).

Formant transition analysis:-

Traditionally formant measurement has been associated with the periodic section of the waveform. Formants basically reflect the vocal tract shape, being its resonant frequencies. Hence the formant transitions have been observed to reflect place of production (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). Although data on formant transition for dental plosive is not available extensively, it may be assumed to be similar to that of alveolar plosives, the difference being a smaller cavity in front of the aperiodic sound source. The slopes of formant transitions have been demonstrated to vary as a function of the adjacent vowel (Cooper, Delattre, Liberman, Borst & Gerstmanet, 1952). When the following vowel is [a], F1 transitions have been observed always to rise from a low frequency locus in the transient for both velars and alveolars. F2 transitions usually decrease in frequency with a faster rate of decrease for alveolars compared to velars. This rate of decrease may be expected to be faster still in the case of dentals. The F3 transition is found to be rising in velars and falling in the case of alveolars. Typically spectral characteristics of velars and dental stop consonants may be assumed to resemble those shown in Fig.4.2.2.

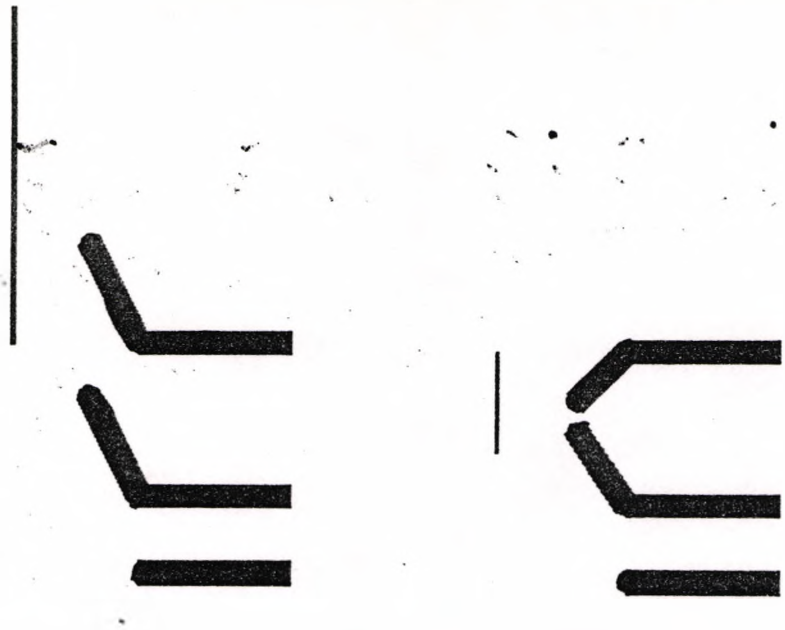


Fig.4.2.2:- Formant transitions and Bursts representing the syllables [ṯa] ,[ka]

Furthermore, the F2 frequency has been observed to be more correlated with place of articulation in vowels as compared to F1 and F3 (Ladefoged, 1972). Traditionally formant frequencies have been largely measured in the periodic portion of the plosive sound. In a few spectrograph samples it was observed that transitions were almost absent in the vowel portion. It could not be ascertained whether this was due to child speech or because of stronger and longer aspiration in Indian languages which have a number of aspirated phonemes. For example, aspirated phonemes are available for both voiced and voiceless plosives and affricatives. Hence transitions may not be present in the vowel portion of the initial CV. However, the formants are basically vocal tract, resonance characteristics. Hence it may be possible to measure the formants in the aperiodic portion of the waveform. The present study attempts to measure the F2 resonance in different segments of the consonant, before the periodic vowel portion.

Other acoustic parameters:-

In addition to the above mentioned acoustic parameters, the velar and dental plosive may influence the voice onset time (VOT), and the formant frequencies of the following vowel, its length and spectral characteristics (Lisker & Abramson, 1964; Kewley-Port, 1983). The low back vowel [a] after initial [$\underline{t}^h$] may be made somewhat forward relative to its articulation after [k^h]. Thus while establishing production differences in velar and apical plosives it is important to measure the VOT and the F2 of vowel [a].

The present study will measure the following acoustic parameters in order to ascertain whether there is significant acoustic difference in the velar and dental initial aspirated voiceless plosive minimal pairs attempted by children with fronting of velars and those with no production errors:-

i) The F2 related peak in the transient, frication and aspiration segments of plosives,

ii) F2 of the following vowel,

iii) Duration of various segments of plosives and following vowel,

iv) Voice onset time, and

v) The Spectral characteristics of various segments of the plosive.

4.3.1 Experimental Procedure

4.3.1.1 Subjects:-

Subjects included children allocated to both experimental and control groups.

i)Experimental group:- Ten subjects (7 boys, 2 girls and one women of 20 years) with velar fronting participated in this study. The children who fronted velars had a mean age of 5.7 years, which ranged from 5;2 to 7 years. All the subjects had no middle-ear infection, hearing loss, language disorder, and/or cognitive deficits. A Photo articulation test in the language spoken at home, revealed that all subjects fronted velars and did not demonstrate errors in any other class of speech sounds. Further testing with a larger set of words containing velars revealed that all subjects fronted both voiced and voiceless velar plosives in all positions (Appendix VI). All ten subjects participated in one production task and three perception tests. All the subjects in this study were bilingual, speaking both languages at home and in school. (By bilingual here it is to be understood that both were spoken fluently but one `leads' in linguistic facility being the language spoken at home.) Furthermore, eight of these subjects had knowledge of English as they were studying in an English medium school. Although it would have been preferable to include subjects from one language background, bilingual speakers were included as in a cosmopolitan city like Bombay it is very difficult to find children who are not exposed to both these languages. The subjects in this group will be referred to as ESs1, ESs2, ESs3, ESs4 ESs5, ESs6, ESs7, ESs8, ESs9, and ESs10.

ii) **Control group :-** Two control groups were included:-

Control group I consisted of ten children with normal speech, cognitive, language and hearing skills matched in age, sex and mother tongue to the subjects in the experimental group. Five children were randomly selected from these for participating in the production task (2 girls and 3 boys in the age group 5;2 years to 5;8 years with a mean age of 5;5 years). These subjects are the same subjects mentioned in the pilot study and referred to as CSs1, CSs2, CSs3, CSs4 and CSs5.

Control group II consisted of four trained adult listeners who were experienced speech scientists mainly involved in developing speech analysis and synthesis systems for man-machine interaction by voice. However, none of them had any formal training in narrow phonetic transcription or experience in transcribing abnormal speech. They will henceforth be referred to as ASs1, ASs2, ASs3, and ASs4, of which ASs1 is a native speaker of Hindi, and the most experienced in perceptual analysis(over 20 years in the field) and being familiar with the I.P.A.

4.3.1.2 Speech stimuli:- In an attempt to 'neutralize' the effect of `bilingualism' as an extraneous variable, minimal pairs meaningful to both languages were selected. The following contrasts were included from the Marati and Hindi languages:-

Marati		Hindi	
/k^halI/	`down'	/k^halI/	`empty'
/$\underline{t}^h$alI/	`plate'	/$\underline{t}^h$alI/	`plate'
/palI/	`lizards'	/palI/	`island'
/halI/	`green worm'	/halI/	`green worm'

Line drawings representing words in the child's first language were selected for all activities for each child (Appendix IV). For example, a child with Hindi as his/her language spoken at home was shown the pictures of `empty', `island', `plate' and `strange worm'. Ten repetitions of the stimulus words were randomized to form two separate lists of 40 (4X10) words in Marati and Hindi (Appendix V).

4.3.1.3 **Production task:-** The production task consisted of a picture naming task. Recordings were made of subjects in experimental group speaking the 40 words in one of the lists using a monophonic cassette tape recorder. A `repeat-after-me' task was employed where the child failed to name a word in sufficient isolation. The microphone was kept eight inches in front of the mouth. All recordings were made in the clinic/school in quiet room conditions. Thus in all a total of 40 words were recorded from each subject, giving a total of 400 audio tape recorded tokens of the four stimulus words. In order to avoid fatigue the recording was conducted in two sessions, with 20 words being recorded in each session. The 100 audio tape recorded tokens of /k^halI/ and /$\underline{t}^h$alI/ spoken by control group I in the pilot study were also included for detailed acoustic analysis.

4.3.1.4 <u>Acoustic analysis:</u>-

The recorded stimulus words were digitized at 16kHz with a 12 bit quantization using the Sensimetrics system for acoustic analysis. The wide band (WB) spectrograms generated with a window size of 96 samples and a Fast Fourier Transform (FFT) interval of 1.62 ms were visually examined to identify the following segments of the initial plosive: transient (tr), frication (fr), aspiration (as), and the subsequent segments [a], [l] and [I] (Figure 4.2.1). The onset of glottal pulsing was often identified by examining narrow band spectrograms (window size of 384 samples) and also the speech waveform. VOT was measured from the beginning of the transient to the onset of glottal pulsing. Bearing in mind the problems in precise formant tracking in areas of rapid movement in child speech and especially where associated with aperiodicity, it was decided to employ short-term LPC averaging technique for estimating F2 in the aperiodic segments mentioned above. It may be noted that this approach was not used while measuring F2 of the vowel [a] as F2 was more readily tracked within the periodic section.

The boundaries of the transient(tr), frication(fr) and aspiration (as) portions were identified and marked for deriving their average LPC (order 24) spectra. By selecting a high order of LPC, the average LPC spectra had a number of spurious formant peaks. However, in using the Sensimetrics speech system it is possible to retain the FFT spectrogram (WB) in the segment not included for averaging. Thus by examining both the FFT and LPC areas of the spectrogram it was possible to identify the correct F2 related peak in the average LPC spectrogram (Fig.4.2.1a, 4.2.1b, 4.2.1c, 4.2.1d, 4.2.1e, 4.2.1f). In Figure 4.2.1a, 4.2.1b, 4.2.1c, 4.2.1d, 4.2.1e, and 4.2.1f, the upper screen displays the WB spectrogram (FFT) with the respective segment averaged in LPC format. This special feature of Sensimetrics made formant tracking in high pitched voices and aspirated more easier and accurate. It may be observed that in Figures 4.2.1a, 4.2.1b, 4.2.1c, 4.2.1d, 4.2.1e, and 4.2.1f to view the FFT of the segment for which the average LPC spectra is shown in the lower right hand corner, the other figures of the same sample would have to be referred. For example, In figure 4.2.1a the transient segment in the upper screen is an order 24 LPC spectrum. If the FFT spectrogram of the transient segment is to be visually examined then refer either figure 4.2.1b or 4.2.1c. Initially the aspiration segment was divided into two segments. That is an initial area with diffuse aperiodic energy and a latter segment with greater high frequency

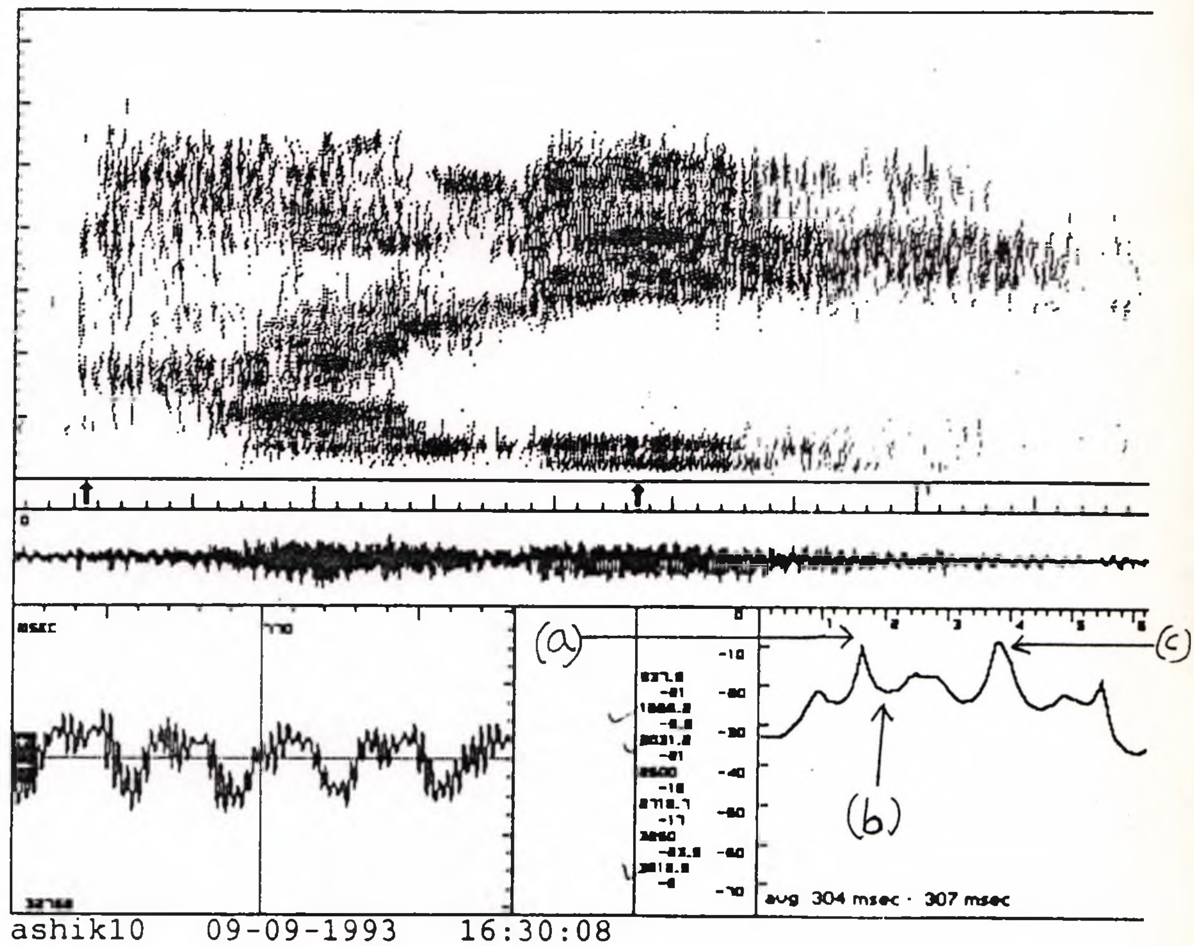
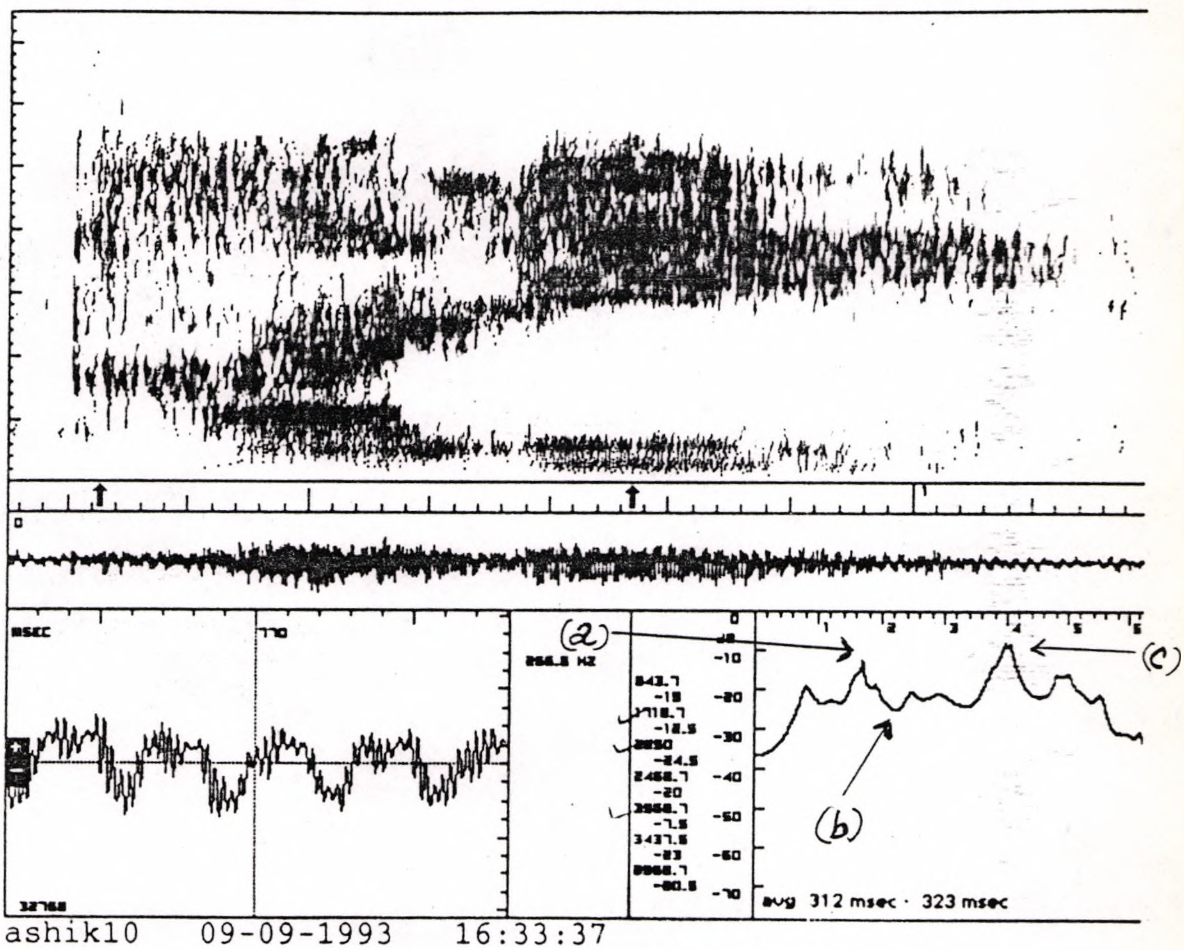


Figure 4.2.1a- Wide band spectrogram along with average LPC spectra of transient segment of /k^h alI/ produced by subject in control group I. (a) F2tr, (b) the lowest energy level between F2tr and 3kHz, and (c) highest peak between 3 and 4kHz.



<u>Figure 4.2.1b:-</u> Wide band spectrogram along with average LPC spectra of post-transient segment of $/k^h alI/$ produced by subject in control group I. (a) F2tr, (b) the lowest energy level between F2tr and 3kHz, and (c) highest peak between 3 and 4kHz.

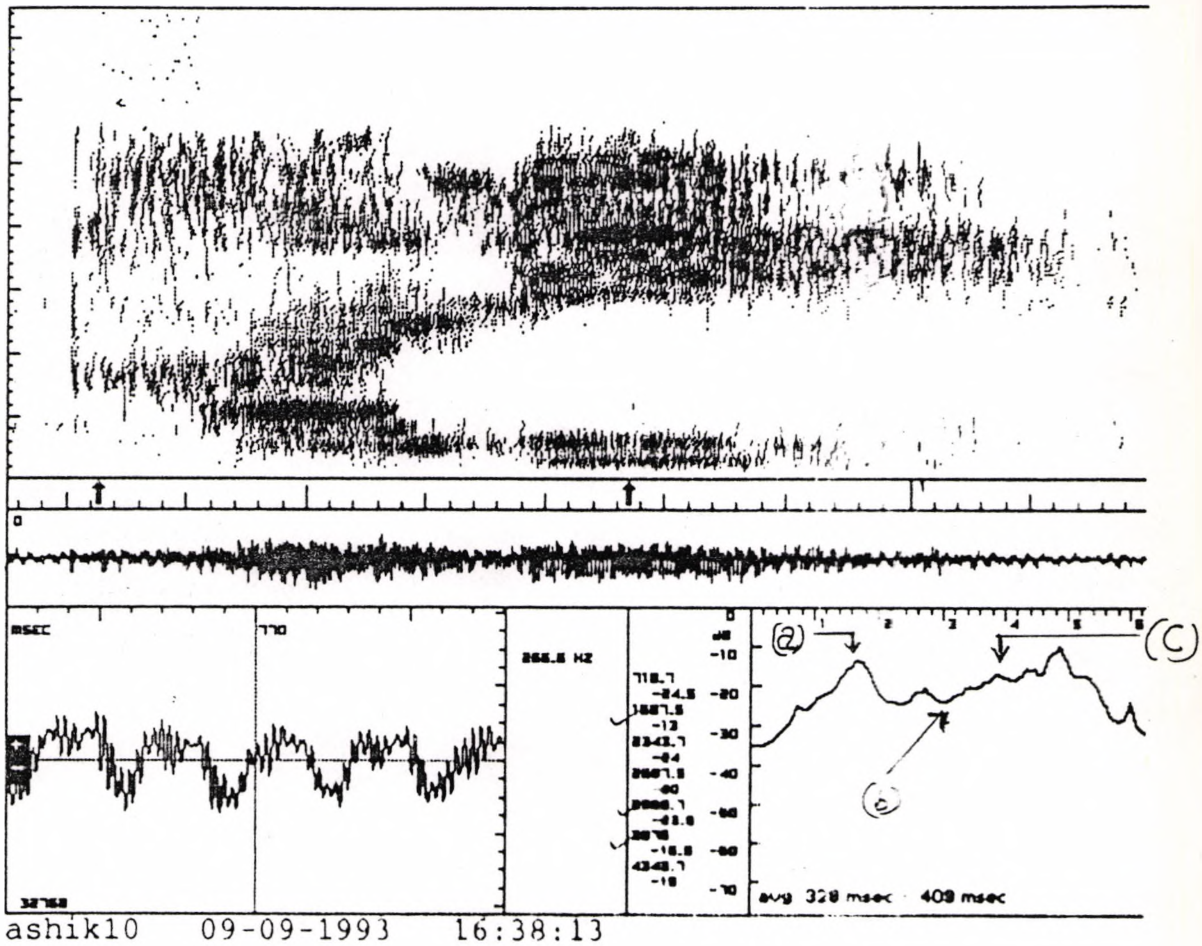
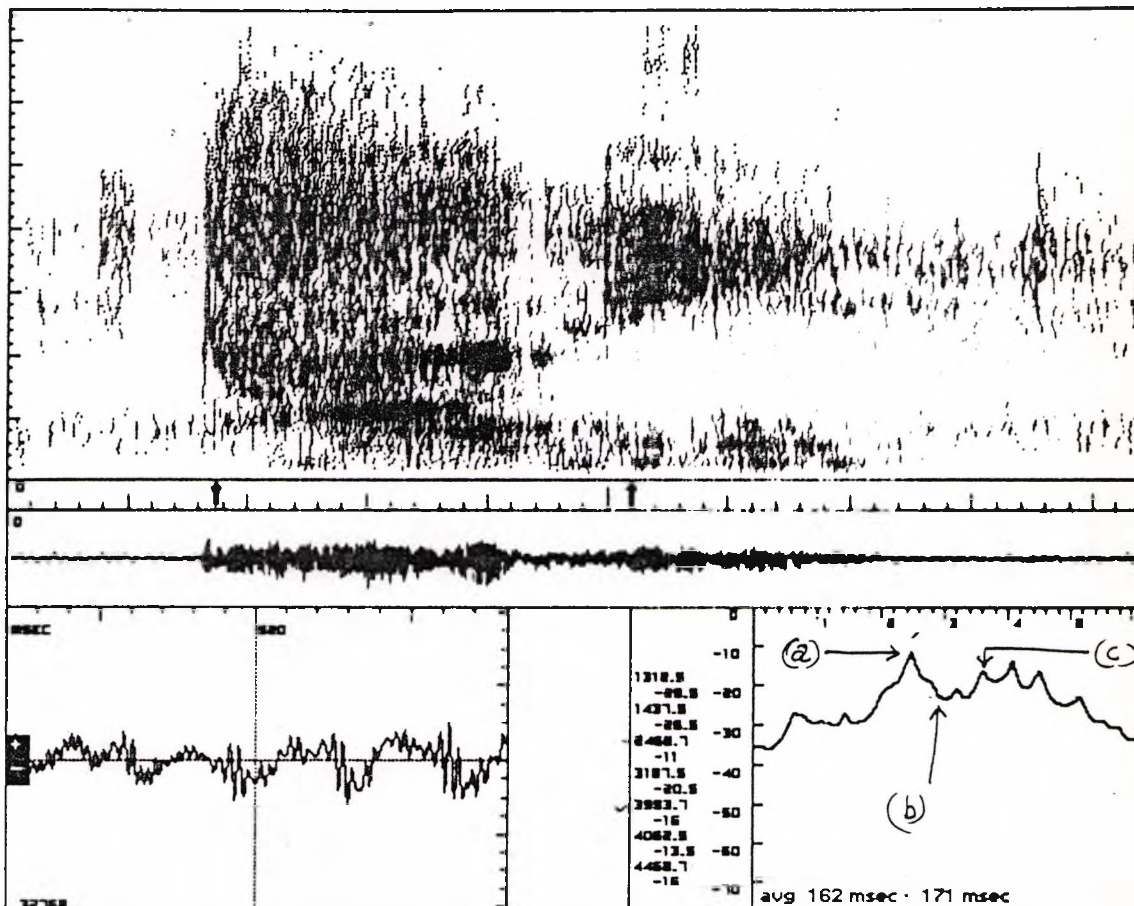


Figure 4.2.1c:- Wide band spectrogram along with average LPC spectra of aspiration segment of /k^h alI/ produced by subject in control group I. (a) F2tr, (b) the lowest energy level between F2tr and 3kHz, and (c) highest peak between 3 and 4kHz.



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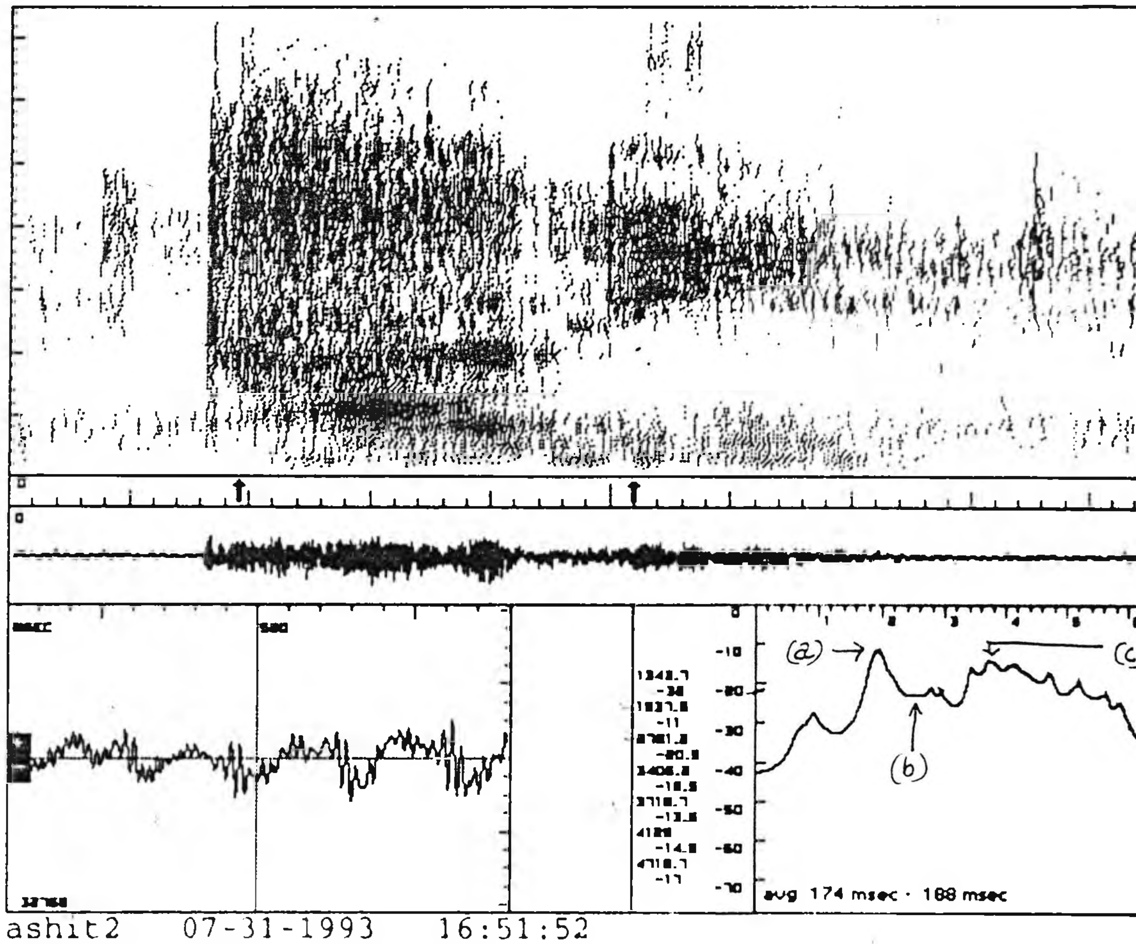
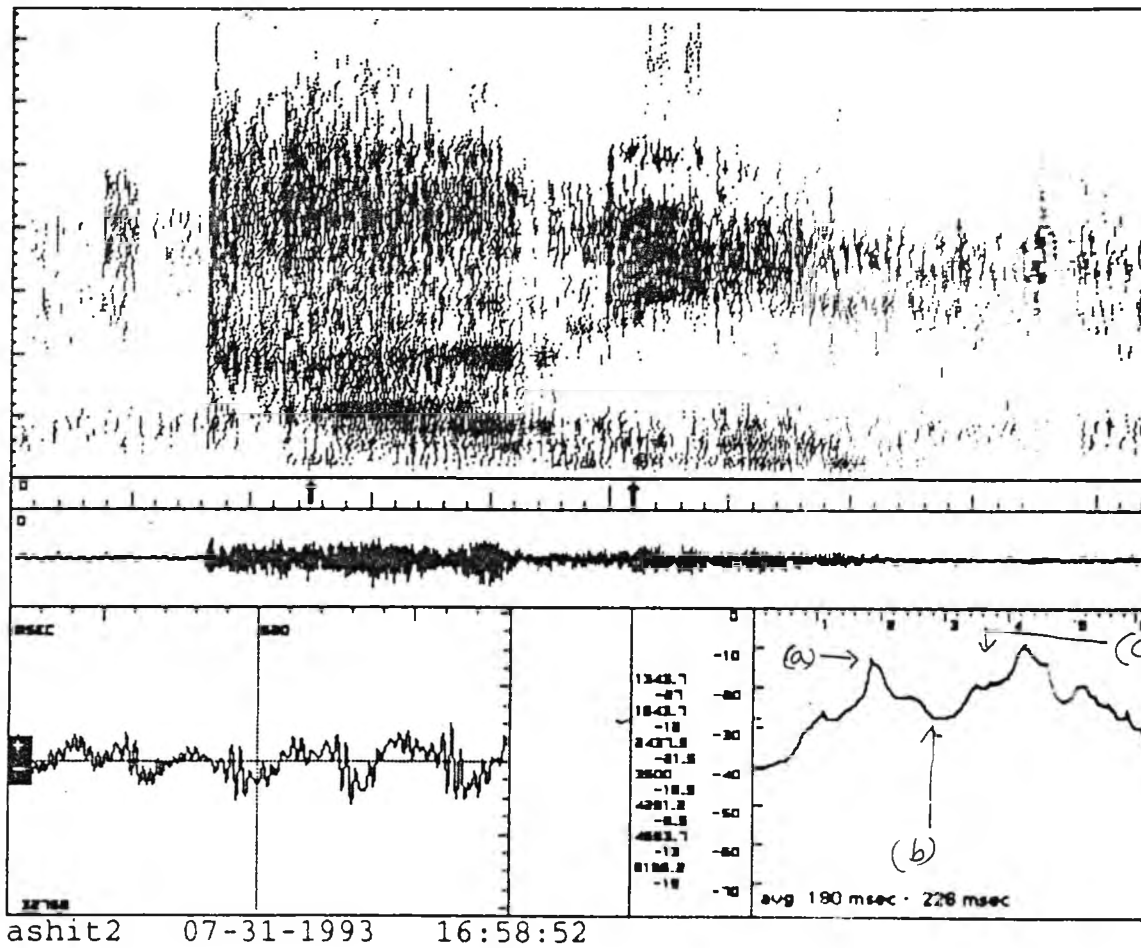
<u>Figure 4.2.1d:-</u> Wide band spectrogram along with average LPC spectra of transient segment of /t^h alI/ produced by subject in control group I. (a) F2tr, (b) ILfr value cannot be measured as the lowest energy level between the F2tr and 3kHz reaches lowest level beyond 3kHz, and (c) highest peak between 3 and 4kHz.



<u>Figure 4.2.1e:-</u> Wide band spectrogram along with average LPC spectra of post-transient segment of /$\underline{t}^{h}$alI/ produced by subject in control group I. (a) F2tr, (b) the lowest energy level between F2tr and 3kHz, and (c) highest peak between 3 and 4kHz.



<u>Figure 4.2.1f:-</u> Wide band spectrogram along with average LPC spectra of aspiration segment of /t^h alI/ produced by subject in control group I. (a) F2tr, (b) the lowest energy level between F2tr and 3kHz, and (c) highest peak between 3 and 4kHz.

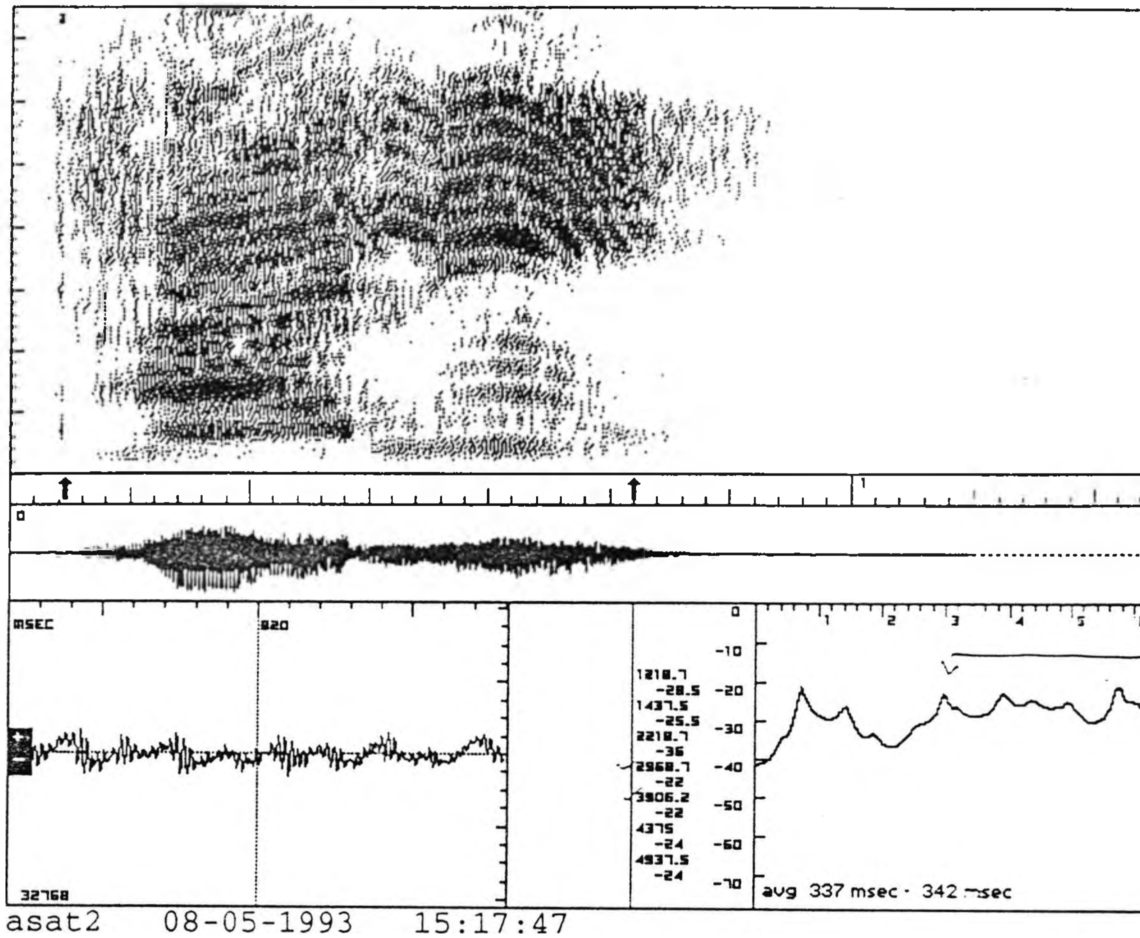


Figure 4.2.1g:- Wide band spectrogram along with average LPC spectra of transient segment of /$\underline{t}^h$alI/ produced by a subject on control group I. The ILtr could not be measured due to F2tr being close to 3kHg.

energy (Figures 4.2.1a). However, as the intra-speaker variability in the duration of these segments was very high, along with a lack of reliability in identifying the segments, this procedure was dropped from the study.

The <u>transients</u> of [k^h] and [$\underline{t}^h$] were generally identifiable as a thin, fairly continuous vertical line on the WB spectrogram. Segmental boundaries were confirmed with the presence of sudden changes in amplitude of the speech waveform (Fig.4.2.1b, 4.2.1e). The <u>frication</u> component of [k^h] and [$\underline{t}^h$] was identifiable in some WB spectrograms as a region of greater energy at a circumspect frequency band corresponding to the F2 of vowel [a] and a sudden decrease in energy in the higher frequencies in the same time domain (Fig. 4.2.1a, 4.2.1b, 4.2.1d, 4.2.1e). Segmental boundaries were occasionally confirmed with the presence of sudden decrease in energy in the speech waveform. The frication segment was often not identifiable in the WB spectrogram. In such cases a <u>post-transient</u> segment of 3ms was used for deriving the average LPC spectrum. Henceforth, in this paper the term \`<u>frication</u>' and \`<u>post-transient</u>' will be treated as referring to the same segment of analysis. The aspiration segment was visually observed to have an acoustic pattern similar to that of the following vowel [a] but aperiodic in nature (Fig.4.2.1a, 4.2.1b, 4.2.1d, 4.2.1e). The duration (D) of the acoustic signal from which the average LPC spectra derived was noted as Dtr, Dfr, Das.

Frequency and intensity values of the spectral peak corresponding to the F2 of the vowel [a] were measured from each of the LPC spectra (F2tr, IF2tr, F2fr, IF2fr, F2as, and IF2as respectively for each of the segments (see Figure 4.2.1b, 4.2.1d, 4.2.1f)). In order to avoid confusion between formant two traditionally measured in the periodic portion of the vowel, these values will be henceforth referred to as `F2 related peak'.

The averaged LPC spectra of the initial 26 ms of the plosive has been described as rising in intensity with increase in frequency above 1kHz in the case of alveolar stops, while the spectrum for velar plosives has been described as having a peak between 1-2 kHz which is the dominant peak above this frequency and up to 5kHz (Stevens & Blumstein, 1978 and Blumstein & Stevens, 1979). During analysis it became apparent that the spectral shape may be important in distinguishing velars and dentals in addition to the F2 related peaks. As a result, a further measure within averaged LPC spectra was made, namely the intensity of (Fig. 4.2.1a to f):-

a) the lowest energy level between the peak corresponding to F2 of the vowel [a] and 3kHz ....(1)

and,

b) the highest peak between 3 and 4kHz ......(2)

Since the intensity measures of frequency vs. intensity display are relative, the above two intensity measures were subtracted form the intensity of the F2 related peak in the average LPC spectra of the respective segments. The difference in F2 related peak and intensity measure (1), was recorded as ILtr, ILfr, and ILas, for transient, post-transient and aspiration segments respectively 4.2.1a, 4.2.1b, 4.2.1c. The difference in F2 related peak and intensity measure (2), were noted as IHtr, IHfr, IHas, for transient, post-transient and aspiration segments respectively (Figure 4.2.1a, 4.2.1b, 4.2.1c 4.2.1d, 4.2.1e, and 4.2.1f).

The F2 of the vowel [a] at the beginning of vowel steady state was located and its frequency noted (F2[a]) (Fig.4.2.1). The duration of vowel [a] segment was measured from onset of glottal pulsing to beginning of F2 or F1 transition to the phoneme /l/. WB Spectrograms using LPC (order 24) were often required to confirm the beginning of F2 or F1 transition to the phoneme /l/. During data collection it was observed that the subjects often differed in pitch and tempi of speech. Since these two factors are extraneous variables which may effect other acoustic measures, it was felt necessary to measure these two parameters in order to ascertain their influence. The duration of the two words was measured from the onset of burst to the cessation of the second formant of the final vowel and/or the voice bar. The F0 was measured within the early steady state of vowel [a]. A total of 13 different measures was therefore made namely,

1) F2 related peak in transient segment (F2tr).

2) F2 related peak in post-transient segment (F2fr).

3)F2 related peak in aspiration (F2as).

4)F2 of [a] (F2[a]).

5)Duration of transient (Dtr).

6)Duration of post-frication segment.

7)Duration of aspiration (Das).

8)Voice onset time (VOT).

9)Duration of vowel [a] (D[a]).

10)Duration word (Dwrd).

11)Fundamental frequency (F0).

12)The difference between intensity of F2 related peak and intensity of the lowest energy level between the peak corresponding to F2 of the vowel [a] and 3kHz in the average LPC spectra of the respective segments (ILtr, Ilfr, and ILas).

13)The difference between intensity of F2 related peak and intensity of the highest peak between 3 and 4kHz in the average LPC spectra of the respective segments (IHtr, IHfr, and IHas).

4.3.1.5 <u>Perceptual analysis:</u>-

Perceptual analysis of data is an integral part of acoustic analysis. The digitized audio recordings of five /k^halI/s and /$\underline{t}^h$alI/s attempted by each subject in the experimental group was played back to Subjects ASs1, ASs2, ASs3, and ASs4, who were required to transcribe the initial consonant for each word. Since subjects ASs2, ASs3, and ASs4 were not familiar with I.P.A. required for narrow transcription, they were requested to indicate whenever they felt difficulty in confirming whether the initial consonant was either a clear-cut velar or dental consonant. They were also encouraged to specify if they felt that the initial consonant was "velar-like" or "dental-like" rather than a clear $/k^h/$ or $/\underline{t}^h/$. Usually the term "velar-like" referred to the initial apical phoneme in which either double articulation was perceived or backing. The term "dental-like" referred to the initial apical phoneme which was not a distinct dental sound.

Subject ASs1 not only participated in the above exercise but also transcribed the remaining five $/k^h$alI/s and five $/\underline{t}^h$alI/s attempted by all subjects in the Experimental group. This transcription was compared to the investigator's transcription to ascertain inter-transcriber reliability.

4.4 Results

The stimulus words attempted by the experimental group were analysed using both perceptual and acoustic analysis approaches. In the case of control group I acoustic analysis procedure alone was applied.

4.4.1. Results of perceptual analysis of /k^halI/ and /t^halI/ attempted by subjects in experimental group:-

The phonetic transcription for the initial consonant in the production output of each subject in the experimental group was done by adult subject ASs1 and the present investigator. There was an overall 92% agreement in the transcription between the two transcribers. In the transcriptions where there was no agreement, the transcription of ASs1 was retained as, experimenter bias was feared to interfere in the case of the present investigator. Furthermore, as both ASs1 and the present investigator are not very familiar with diacritic markers, often the transcribers resorted to making remarks such as "velar-like" whenever they perceived any aspect of velar in an apical sound such as slightly back placement of tongue tip or tongue body. After the transcription the investigator discussed with ASs1 whether the "velar-like" could be interpreted as palatalized, velarized, or pharyngealized. The phonetic transcription done by subject ASs1 is given in

Table 4.2.A. Subject ESs1 and ESs2 were observed to front all velar aspirated sounds in the stimulus words and replaced it with a sound which was transcribed as a voiceless dental aspirated plosive. In case of ESs2 , seven of the velar initial words were judged to contain an initial aspirated voiceless dental sound, two of the attempted aspirated velar sounds were transcribed as dental plosives with frication and one of the tokens was identified as velar. Of the initial voiceless dental aspirated sounds attempted by this subject, one was transcribed as palatalized and three tokens as containing frication along with dental plosion.

Table 4.2.A:- The results of Perceptual analysis of production output (o/p) of target /k^{h}alI/ and /t̲^{h}alI/ attempted by subjects in experimental group.

Subject	/k^{h}alI/h^{alI}/		/t̲^{h}alI/	
	No. of Tokens	O/P of [k^h]	No. of Tokens	O/P [t̲^{h}]
ESs1	10	[t̲^{h}]	10	[t̲^{h}]
ESs2	7 2 1	[t̲^{h}] [θ] [k^h]	6 3 1	[t̲^{h}] [θ] [t̲^{h}] palatalized
ESs3	10	[t̲^{h}]	10	[t̲^{h}]
ESs4	10	[t̲^{h}]	8 2	[t̲^{h}] [ʈ^h]
ESs5	9 1	[t̲^{h}] [t̲^{h}] ?palatalized	9 1	[t̲^{h}] [ʈ^h]
ESs6	9 1	[t̲^{h}] [ʈ^h]	9 1	[t̲^{h}] [t̬^{h}]
ESs7	9 1	[t̲^{h}] [h] pharyngeal ?	8 2	[t̲^{h}] [ʈ^h]
ESs8	2 5 1 2	[t̲^{h}] palatalized? [k^h] [θ^h] [d̲^{h}]	10	[t̲^{h}] not clear
ESs9	4 3 1 2	[t̲^{h}] [t̲^{h}] not clear [k^h] [ʈ^h]	6 2 2	[t̲^{h}] [t̲^{h}] not clear [ʈ^h]
ESs10	7 1 1 1	[t̲] [t̲] labialized ? [t̬] [ħ]	9 1	[t̲] [ʈ]

Subject ESs4 tended to replace dental aspirated voiceless plosives for the target velar aspirated plosive. However, while targeting dental initial stimulus words she tended occasionally to use an alveolar or retroflex voiceless aspirated plosive. In the case of subject ESs5, nine targeted velar tokens were transcribed as being dental. However, one token was transcribed as having a "velar element" which is noted as palatalized in table 4.2.A. One of the initial voiceless dental aspirated word was replaced by a voiceless plosive which was made towards post-alveolar, which is noted as palatalized in table 4.2.A. Subject six replaced a velar aspirated plosive with an aspirated voiceless retroflex plosive. While targeting dental initial stimulus words, one token was transcribed as "having a voicing component". Subject ESs7 tended to use considerable aspiration in his production. One of the velars was produced with strong aspiration which was transcribed as being either a pharyngeal or a glottal fricative. Two of his tokens for the target dental initial word was transcribed as retroflex. Subject ESs8 was the 20 year old subject mentioned earlier. Five of her tokens were transcribed as clear cut voiceless velar aspirated sounds. Two were transcribed as having elements of velar place, one as a voiceless dental fricative and two others as voiced dental plosives. All the dentals attempted, were judged not to be distinct dental plosives. The remark "not clear" refers to where the investigators felt that the articulatory contact was not made sharply. Of the ten velar initial stimulus word attempted by subject ESs9, two were transcribed as retroflex, one as "velar-like", three as dental but not clear, and the rest as clear cut dental aspirated plosives. Of the ten dental targets attempted two were transcribed as retroflex, two as being "dental-like", and the rest as clear cut aspirated voiceless dental plosives. Subject ESs9 was also observed to use very strong aspiration and a breathy vowel for [a] while attempting the minimal pairs. Subject ESs10 tended to produce unaspirated plosives. In the case of the 10 velar initial words attempted, one token was transcribed as being labialized and another as being voiced dental, and one token had an initial voiceless glottal fricative. In her production of the dental initial words, most were judged as dentals except for one token which was transcribed as being a retroflex plosive.

In case of the less experienced transcriber, transcription agreement among ASs2, ASs3 and ASs4 was reached for 62 out of 100 tokens transcribed. Of these greater agreement was observed for the tokens of /$\underline{t}^h$alI/ (36 out of 50 tokens) than for attempted /k^halI/ (26 out of 50 tokens).

Subject ASs2 was a native speaker of Hindi and had about five years experience in listening to speech sounds and describing them. He heard all productions of Subjects ESs1, 2, 3, 4, 5, 6, 7, and 9 as containing /$\underline{t}^h$/ initial consonant. He identified four of the five attempted /k^halI/s by ESs8 as containing an initial /k^h/ consonant. In the case of output from subject ESs10, he expressed difficulty in deciding what the initial consonants were.

Subject ASs3 was also a native speaker of Hindi. However, he had about one year experience in listening to speech sounds and describing them. ASs3 heard all ten initial consonants of stimulus word spoken by ESs1 as /$\underline{t}^h$/ consonant. In the case of the recording from subject ESs2, three of the targeted /$\underline{t}^h$alI/s were transcribed as being "like a dental", rather than a distinct /$\underline{t}^h$/. All the initial consonants of words spoken by subject ESs3 were identified as /$\underline{t}^h$/, except for one of the targeted /$\underline{t}^h$alI/ where the transcriber could not decide between velar and dental. In case of ESs4, the initial consonant of the stimulus word /k^halI/ was transcribed as being "dental like", while one initial consonant of /$\underline{t}^h$alI/ was transcribed as an aspirated retroflex plosive. The rest of the productions were identified as /$\underline{t}^h$/. In case of ESs5, one initial consonant of attempted /k^halI/ was transcribed as being "dental like" , while two of the /$\underline{t}^h$alI/ was also noted as "dental like" rather than a clear cut /$\underline{t}^h$/. In case of ESs6, the transcriber identified two attempted /k^halI/ as having a "dental like" initial consonant, while the rest were transcribed as /$\underline{t}^h$/. In case of ESs7, all initial consonants were transcribed as /$\underline{t}^h$/, except for one stimulus word /k^halI/ for which the transcriber could not be sure whether a velar or dental sound was present. In the case of ESs8, the listener ASs3 transcribed two of the attempted /k^{h}alI/s as containing a word initial voiceless aspirated retroflex plosive. In the case of the recordings from subject ESs9, all the initial consonants were transcribed as /$\underline{t}^h$/, except for one /$\underline{t}^h$alI/ which was transcribed as a word with initial voiceless aspirated retroflex plosive. Transcriber ASs3 expressed overall difficulty in deciding whether the initial consonant was a velar or dental for words attempted by subject ESs10.

Adult listener ASs4 was a native speaker of an Indo-dravidian language Telegu. He had spoken language skills in Hindi and had been residing in a Hindi speaking region for the past five years. He had about five years experience in listening to speech sounds and describing them. The following was the pattern of transcription for each of the subjects in the experimental group by this transcriber:-

ESs1:- All productions were transcribed as being word initial /$\underline{t}^h$/ consonant, except in case of one attempted /$\underline{t}^h$alI/ which the transcriber found ambiguous.

ESs2:- Two production attempts of /k^{h}alI/ were identified as having "velar like" initial consonants. Furthermore, one /$\underline{t}^h$alI/ attempted by the subject was identified as having a "dental like" initial consonant rather than a clear /$\underline{t}^h$/, while another was reported to have an ambiguous initial consonant.

ESs3:- All production attempts of the two stimulus words heard were transcribed as having initial /$\underline{t}^h$/ consonant.

ESs4:- The initial consonant of one /k^halI/ was observed to be ambiguous. Another /$\underline{t}^h$alI/ attempted was observed to have a word initial "dental like" consonant, rather than a distinct /$\underline{t}^h$/.

ESs5 and ESs7:- All production of these subjects were identified as containing word initial /$\underline{t}^h$/ except for one token of /k^halI/, which was transcribed as having a "dental like" initial consonant.

ESs6:- Two of the attempted /k^halI/s were transcribed as containing word initial "dental like" consonant. The rest of the productions were identified as word initial /$\underline{t}^h$/ consonants.

ESs8:- Three of the /k^halI/ attempted by this subject were identified correctly as /k^h/ initial words. Two other attempts of the same word were transcribed as "velar like" and "dental like" initial consonants. One of the /$\underline{t}^h$alI/s attempted was transcribed as "dental like" while the rest were transcribed as distinct voiceless aspirated dentals.

ESs9:- Of the five /k^halI/s attempted by this subject, one token was transcribed as word having initial /$\underline{t}^h$/. Two others were transcribed as having a "velar like " initial consonant and one more as having a "dental like" initial consonant. Most of the dental initial words were transcribed as having distinctly dental aspirate plosives, except for one token which was observed to have an ambiguous initial consonant.

ESs10:- All the productions of this subject were identified as difficult to transcribe.

4.4.2. <u>Results of Acoustic analysis:-</u>

Results were analysed to obtain typical values for each of the acoustic measurement made, and to ascertain whether the difference in the values for /k^{h}alI/ and /t̪^{h}alI/ reached statistical significance.

Subjects ESs1 to ESs7 were analysed as a group so that group statistics could be applied for comparison with the normative values compiled from the values of five subjects from control group I(Norpoth, 1987). Since acoustic parameters co-occur almost simultaneously in the speech wave, Discriminant analysis was applied to study whether various parameters as a whole distinguish between the velar and dental aspirated words and the relative importance of each of the acoustic parameters for making this distinction in the production of control group I and the experimental group (Klecka, 1987). Subjects ESs8, ESs9, and ESs10 were excluded from group data for the following reasons:-

(1)Subject ESs10 produced unaspirated plosives for the target words,

(2)Subject ESs9 inconsistently used breathy vowels, which made measurement of VOT, F2 of vowel [a] difficult, while

(3)Subject ESs8 was the 20 years old who appeared to be in the middle of acquiring velars and had received some therapeutic intervention. However she was included in the study as she appeared to have difficulty knowing when she had said a target velar correctly. These three subjects will be discussed individually later.

4.4.2.1. Results of acoustic data obtained from subjects CSs1 to CSs5 and ESs1 to ESs7:-

Initially the results were statistically analysed to ascertain whether specific differences were present in transient, post-Transient and aspiration segments.

A. F2 related peak in different segments:-

i) Control group I:-

Tables 4.2.1a, 4.2.2a and 4.2.3a present the mean and standard deviation (SD) of the F2 related peak in the average LPC spectra of the transient, post-transient and aspiration segment in [k^h] ~ [$\underline{t}^h$] minimal pair spoken by subjects in control group I. In table 4.2.4a are the mean and SD of F2 of vowel [a] for the velar and dental initial minimal pairs for this group.

Table 4.2.1a:- The mean and SD of **F2tr** measured in the average LPC spectra of **transient** segments in /k^h^alI/ and /t̠^h^alI/ spoken by children in with no production error.

Ss	/k^h^alI/ Mean(Hz)	SD	/t̠^h^alI/ Mean(Hz)	SD.
CSs1.	1999.8	75.1	2359.1	59.1
CSs2.	1965.8	104.0	2454.3	278.5
CSs3.	1793.3	153.9	2585.1	293.4
CSs4.	2118.1	134.6	3271.2	548.6
CSs5.	1992.2	205.5	2728.4	242.0
Group	1963.0	184.5	2679.6	449.2

Table 4.2.2a:- The mean and SD of **F2fr** measured in the average LPC spectra of **post-transient** segments in /k^h^alI/ and /t̠^h^alI/ spoken by children in control group I.

Ss	/k^h^alI/ Mean(Hz)	SD	/t̠^h^alI/ Mean(Hz).	SD.
CSs1.	2074.1	148.4	2367.4	89.0
CSs2.	1890.8	105.2	2343.0	310.6
CSs3.	1692.3	66.5	2193.9	223.8
CSs4.	2162.6	275.9	2843.6	551.5
CSs5.	1976.9	142.0	2512.8	115.7
Group	1959.3	226.4	2452.1	369.1

Table 4.2.3a:- The mean and SD of **F2as** measured in the average LPC spectra of **Aspiration** segments in /k^halI/ and /$\underline{t}^h$alI/ spoken by children in control group I.

Ss	/k^halI/ Mean(Hz)	SD	/$\underline{t}^h$alI/ Mean(Hz).	SD.
CSs1.	2044.7	97.1	2257.7	92.9
CSs2.	1941.0	92.5	2235.7	167.6
CSs3.	1676.2	58.1	1939.3	128.5
CSs4.	2250.5	237.7	2471.3	132.2
CSs5.	1921.7	96.3	2454.8	141.3
Group	1966.8	226.8	2271.8	233.4

Table 4.2.4a:- The mean, the lowest and highest value and SD of vowel [a] formant two for /k^halI/ and /$\underline{t}^h$alI/ spoken by children in control group I.

Ss	/k^halI/ Mean(Hz)	SD	/$\underline{t}^h$alI/ Mean(Hz)	SD
CSs1.	2084.5	73.7	2081.4	76.7
CSs2.	1925.0	63.0	1987.6	36.4
CSs3.	1765.7	96.8	1815.7	80.0
CSs4.	2078.2	194.2	2270.5	59.0
CSs5.	1765.5	274.1	1996.9	137.7
Group	1923.8	211.0	2030.4	170.1

The two factor completely randomised Analysis of Variance (ANOVA) was applied separately for the F2 related peak measured in the initial four segments of the /k^h/~/$\underline{t}^h$/ minimal pair (Subject X [k^h]~[$\underline{t}^h$] Minimal pair) (Norpoth, 1987). The analysis of variance was undertaken separately for the two groups. Since child data has been observed to have high variability, it was felt necessary to consider each child as a variable. The age range of 3years to 7years is a period when considerable spurts in development of speech and language skills take place. This is also true for the individual's anatomical and physiological development of the speech mechanism. Since vocal tract and laryngeal dynamics may be expected to be reflected in speech acoustic measurements, it would not be surprising to obtain large variability in these measurements. Hence in order to account for the difference in absolute value of the acoustic parameters, each subject was treated as a variable. That is, the acoustic measurement may be affected by the `vocal tract' from which the minimal pairs originated. This factor is referred to as the main effect `Subject'. The obtained F-ratio and level of significance is given in Table 4.2.5a.

It may be observed from table 4.2.5a that significant main effects for `Subject' and /k^h/~/$\underline{t}^h$/ Minimal pair were obtained for the F2 related peak for all four segments ($P<.001$). This indicates that the overall control group I subjects differ in the F2 related peak measures. However, each subject maintains a significantly higher F2 related peak for dentals as compared to velars (at $p<.001$). The high level of significance of interaction effects indicates that the difference in F2 related peak for the minimal pairs is different for individual subjects in control group I. From Fig 4.2.3a. it is apparent that for the transient segment the F2tr value for velars spoken by control group I, cluster around 2000kHz, while those for dentals are at 2500Hz with the exception of subject CSs4 who has an extremely high mean at around 3500 Hz. From fig. 4.2.4a, 4.2.5a, and 4.2.6a it is apparent that there is not only a greater spread of F2 related peak values for velars but also a decrease in the difference between velars and dentals for this measure in normal children from transient segment to vowel[a]. However, results of ANOVA indicate that the differences are significant beyond .001 level for both subject and minimal pair effects in all the segments. The lack of significant interaction effects indicates that the difference in F2fr for velars and dentals are similar for all five subjects in control group I. This is apparent in Fig. 4.2.4a where the lines joining the means for all subject (Except CSs2) are nearly parallel to each other. The results are in agreement with Fant's (1973) findings for Swedish aspirated voiceless plosives, that at the instance of release the F2 of velar plosive is lower than those of apical plosive. As expected the F2 related peaks in transients are relatively higher in the child data in the present study. As expected the mean difference in the F2 related peak of the transient between velars and dentals (745.8 Hz) is here substantially larger than those reported by Fant (1973). Whether this is due to child production or to dental plosives cannot be verified from

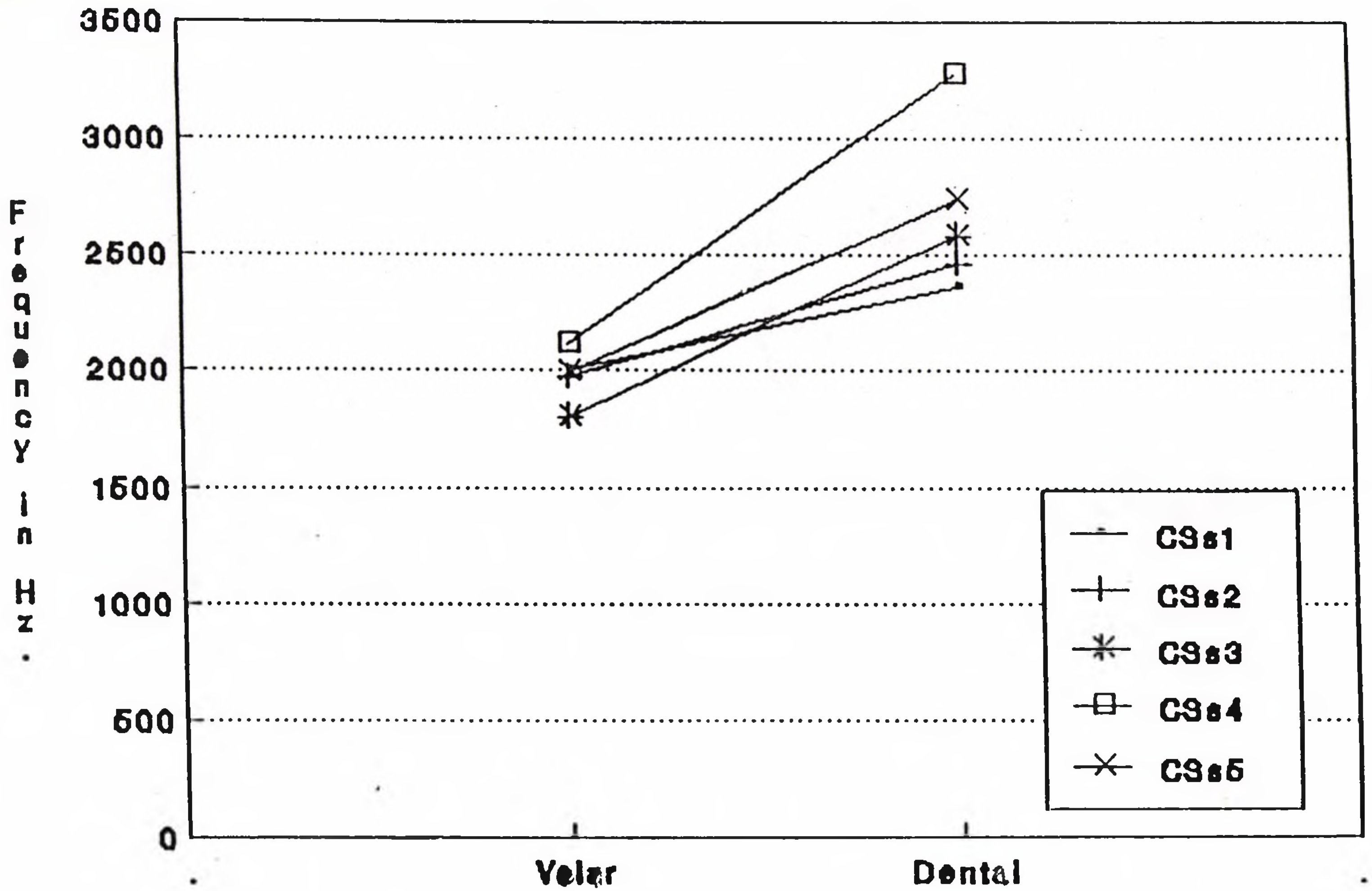


Fig. 4.2.3a:- Mean F2 related peak in LPC spectra of transient segment of velar and dental initial minimal pair spoken by each subject in Control group I.

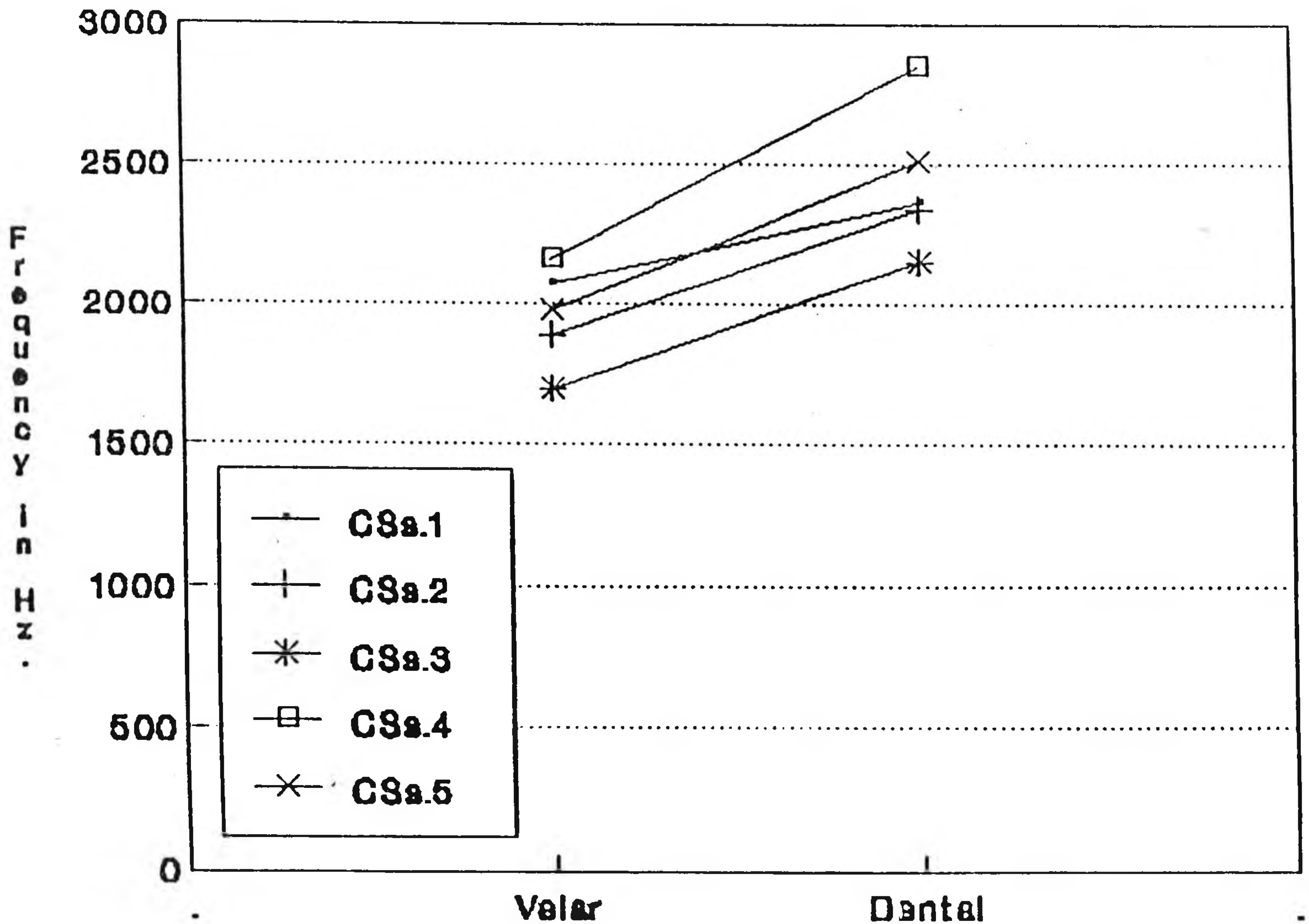


Fig. 4.2.4a:- Mean F2 related peak in LPC spectra of post-transient segment of velar and dental initial minimal pair spoken by each subject in Control group 1.

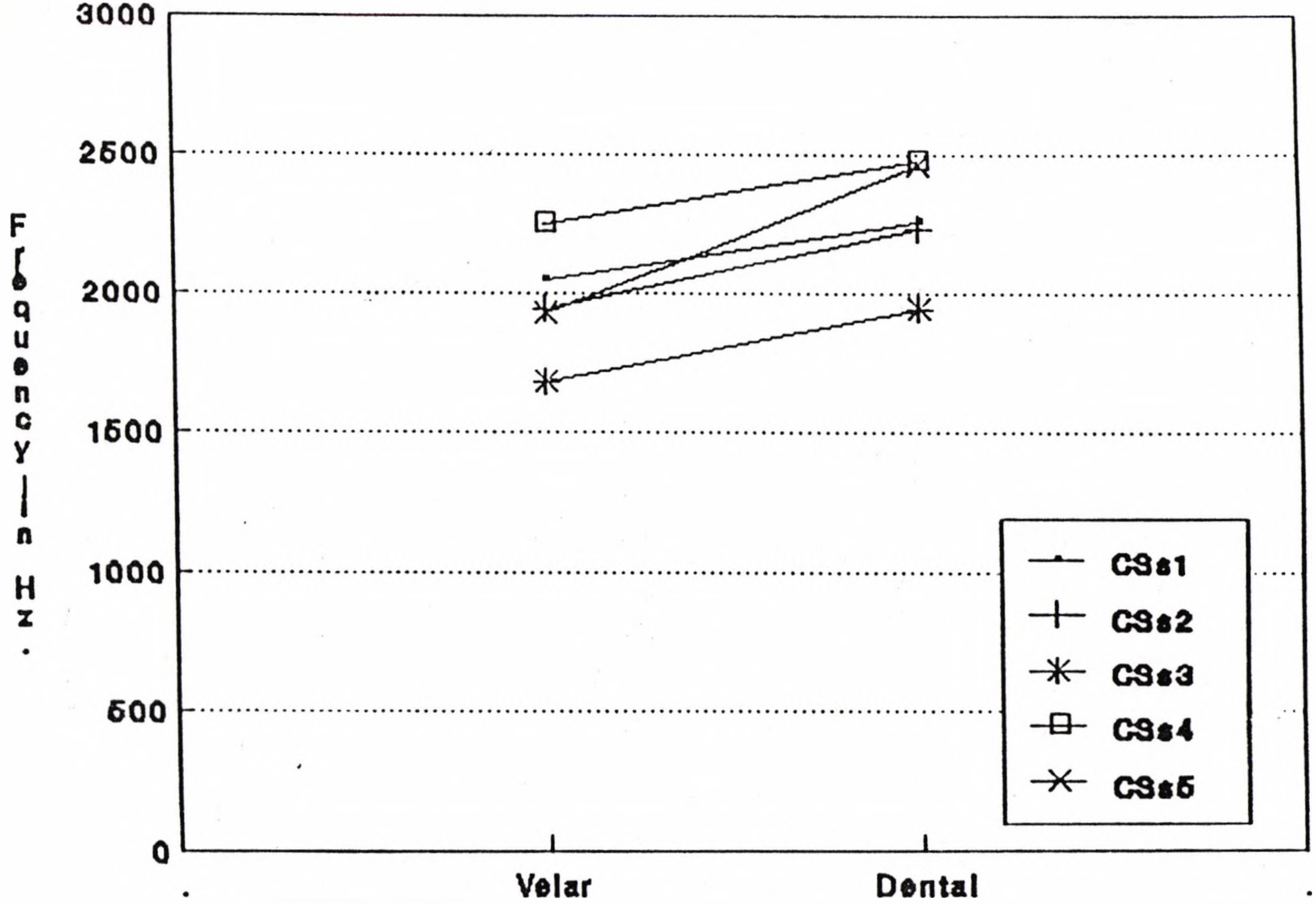


Fig. 4.2.5a: Mean F2 related peak in LPC spectra of aspiration segment of velar and dental initial minimal pair spoken by each subject in Control group I.

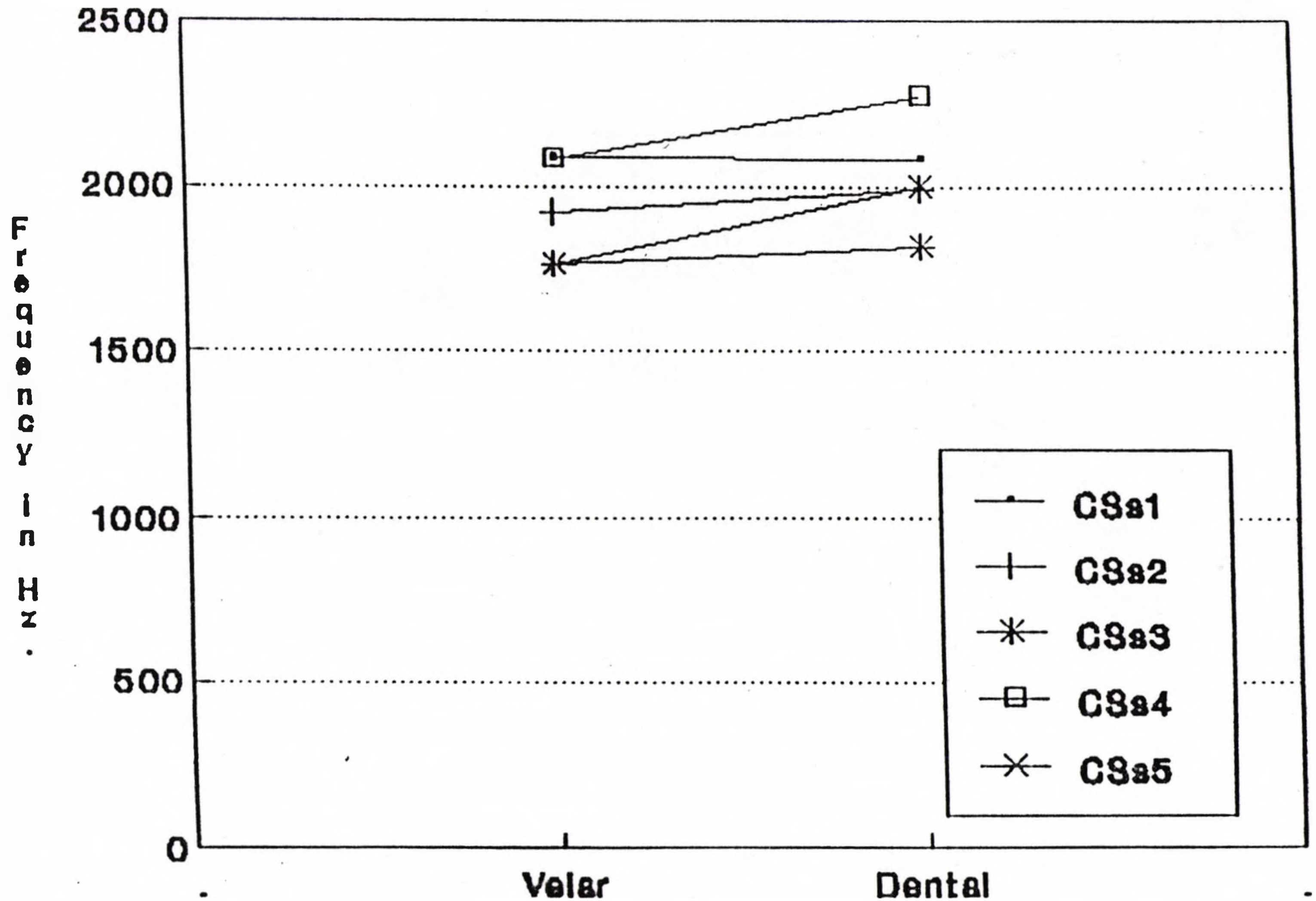


Fig. 4.2.6a:- Mean F2 of vowel [a] in velar and dental initial minimal pair spoken by each subject in Control group I.

the present data. Hewlett (1988) measured the frequency of the highest spectral peak which cannot be compared to the F2 related peak measurement in the current experiment. No attempt was made to measure the highest spectral peak as the nature of the contribution of formant frequencies above 5kHz to speech recognition is not very clear. However, it was observed that the F2 related peak was not always the highest peak in the spectrum for dentals spoken by normal children.

Table 4.2.5a:- The F-ratio and levels of significance for the **F2 of [a] and the F2 related peak** in average LPC spectra for each of the segments in the $[k^h] \sim [\underline{t}^h]$ minimal pair and the sources of variation for the control group I.

Analysis segment	sources of variation	df	F	P
Transient	Subject	4	15.84	.000
	$[k^h] \sim [\underline{t}^h]$ minimal pair.	1	204.7	.000
	Subject X $[k^h] \sim [\underline{t}^h]$ minimal pair.	4	7.7	.000
Post-transient	Subject	4	13.79	.000
	$[k^h] \sim [\underline{t}^h]$ minimal pair.	1	100.22	.000
	Subject X $[k^h] \sim [\underline{t}^h]$ minimal pair.	4	1.63	.175
Aspiration	Subject	4	45.60	.000
	$[k^h] \sim [\underline{t}^h]$ minimal pair.	1	130.77	.000
	Subject X $[k^h] \sim [\underline{t}^h]$ minimal pair	4	4.88	.001
Vowel [a]	Subject	4	28.18	.000
	$[k^h] \sim [\underline{t}^h]$ minimal pair.	1	16.96	.000
	Subject X $[k^h] \sim [\underline{t}^h]$ minimal pair	4	2.99	.023

ii) Experimental group:-

In table 4.2.1b, 4.2.2b, and 4.2.3b are presented the mean and SD of F2 related peak in average LPC spectra of the transient, post-transient and aspiration segments for minimal pair attempted by children who front their velars.

Furthermore, in table 4.2.4b, are the mean and SD of F2 of vowel [a] following the initial consonant ([k^h] and [$\underline{t}^h$]) produced by the same subjects. The individual means for the target minimal pair are presented in the form of a line graph in Figure 4.2.3b, 4.2.4b, 4.2.5b, and 4.2.6b for each of the four segments respectively.

<u>Table 4.2.1b</u>:- The mean and SD of **F2tr** in target velar and dental aspirated initial words attempted by subjects who front their velars.

	/k^hali/		/$\underline{t}^h$ali/	
Ss	Mean(Hz)	SD	Mean(Hz)	SD
ESs1.	2803.9	259.4	2743.8	384.3
ESs2.	2709.5	349.0	2600.0	374.8
ESs3.	2874.9	468.2	2887.6	466.4
ESs4.	2961.0	336.0	3075.0	354.8
ESs5.	2568.6	223.5	2675.0	257.6
ESs6.	2634.5	156.0	2614.2	168.7
ESs7.	3076.7	216.0	3128.2	503.6
Group	2804.2	335.2	2817.7	410.7

Table 4.2.2b:- The mean and SD of **F2fr** in target velar and dental initial minimal pairs attempted by subjects who front their velars.

	$/k^{h}ali/$		$/\underline{t}^{h}ali/$	
Ss	Mean(Hz)	SD	Mean(Hz)	SD
ESs1.	2556.3	234.1	2515.6	286.1
ESs2.	2397.0	419.4	2606.3	375.0
ESs3.	2631.4	437.5	2691.0	515.5
ESs4.	2720.1	152.5	2982.8	355.3
ESs5.	2495.4	378.0	2471.2	191.0
ESs6.	2465.7	181.9	2423.0	210.0
ESs7.	2777.8	393.9	2399.3	246.0
Group	2577.7	343.6	2584.2	361.6

Table 4.2.3b:- The mean and SD of **F2as** in target velar and dental initial words attempted by subjects who front their velars.

	$/k^{h}ali/$		$/\underline{t}^{h}ali/$	
Ss	.Mean(Hz)	SD	. Mean(Hz)	SD
ESs1.	2395.3	140.1	2533.2	103.6
ESs2.	2457.6	170.9	2404.1	311.4
ESs3.	2265.7	310.2	2286.0	212.6
ESs4.	2689.1	135.2	2639.7	181.9
ESs5.	2123.5	151.7	2165.1	165.8
ESs6.	2312.6	131.9	2287.6	177.7
ESs7.	2355.4	178.6	2425.3	211.2
Group	2371.3	240.0	2391.6	244.8

Table 4.2.4b:- The mean and SD of **F2 of vowel [a]** for target velar and dental minimal pairs attempted by subjects who front their velars.

	/k^hali/		/$\underline{t}^h$ali/	
Ss	Mean(Hz)	SD	Mean(Hz)	SD
ESs1.	2231.5	94.7	2413.0	166.4
ESs2.	2146.2	227.8	2137.4	181.5
ESs3.	2109.4	139.1	2131.3	184.6
ESs4.	2478.0	206.2	2375.2	318.1
ESs5.	1993.8	123.9	2010.3	87.1
ESs6.	2125.2	270.0	2296.9	170.1
ESs7.	2273.6	130.7	2243.8	131.6
Group	2194.0	224.6	2229.7	225.4

The two factor completely randomised Analysis of Variance (ANOVA) was applied to the data to ascertain if there was a significant difference in the means for the F2 related peak for each of the segments (Subject X /k^h/~/$\underline{t}^h$ minimal pair) in the minimal pairs /k^hali/ and /$\underline{t}^h$ali/ attempted by the seven subjects in the experimental group. The resultant F-ratio and level of significance for various segments of analysis obtained from the experimental group is given in Table 4.2.5b. From Table 4.2.5b it is apparent that the significant main effects for subject-variable were obtained for this measurement for all four segments ($P<.005$). This indicates therefore, that the experimental subjects as a group differ in the F2 related peak measures for all four segments. This is apparent from figure 4.2.3b, 4.2.4b, 4.2.5b, and 4.2.6b, where clustering of means is observed only for velars in the post-transient segment compared to other segments. The horizontal lines (almost parallel to the x-axis) connecting the mean F2 related peak for target velar and dental plosives indicate that there is no significant difference in their attempted production of /k^h/~/t^h/ for this acoustic measure. This is confirmed by the small F-ratio which did not reach the .05 level of significance. The obtained F-ratios, for the interaction effects (that is, of Subject X /k^h/~/t^h/ minimal pair) indicates that the velar fronting subjects did not maintain significantly different F2 related peak differences in their productions of the two words. From figure 4.2.4b, subjects ESs4 and ESs7 appear to maintain greater mean differences in F2fr values in their production of the target minimal pair. Since interaction just missed reaching significance at .064 level, the Scheffee's test for unplanned comparison was applied and the resultant F-ratio was observed to be significant at the .05 level of significance for subject ESs7 only. This indicates that subject ESs7 had a significantly higher F2 related peak in the post-transient segment for velar initial aspirated plosives compared to dentals.

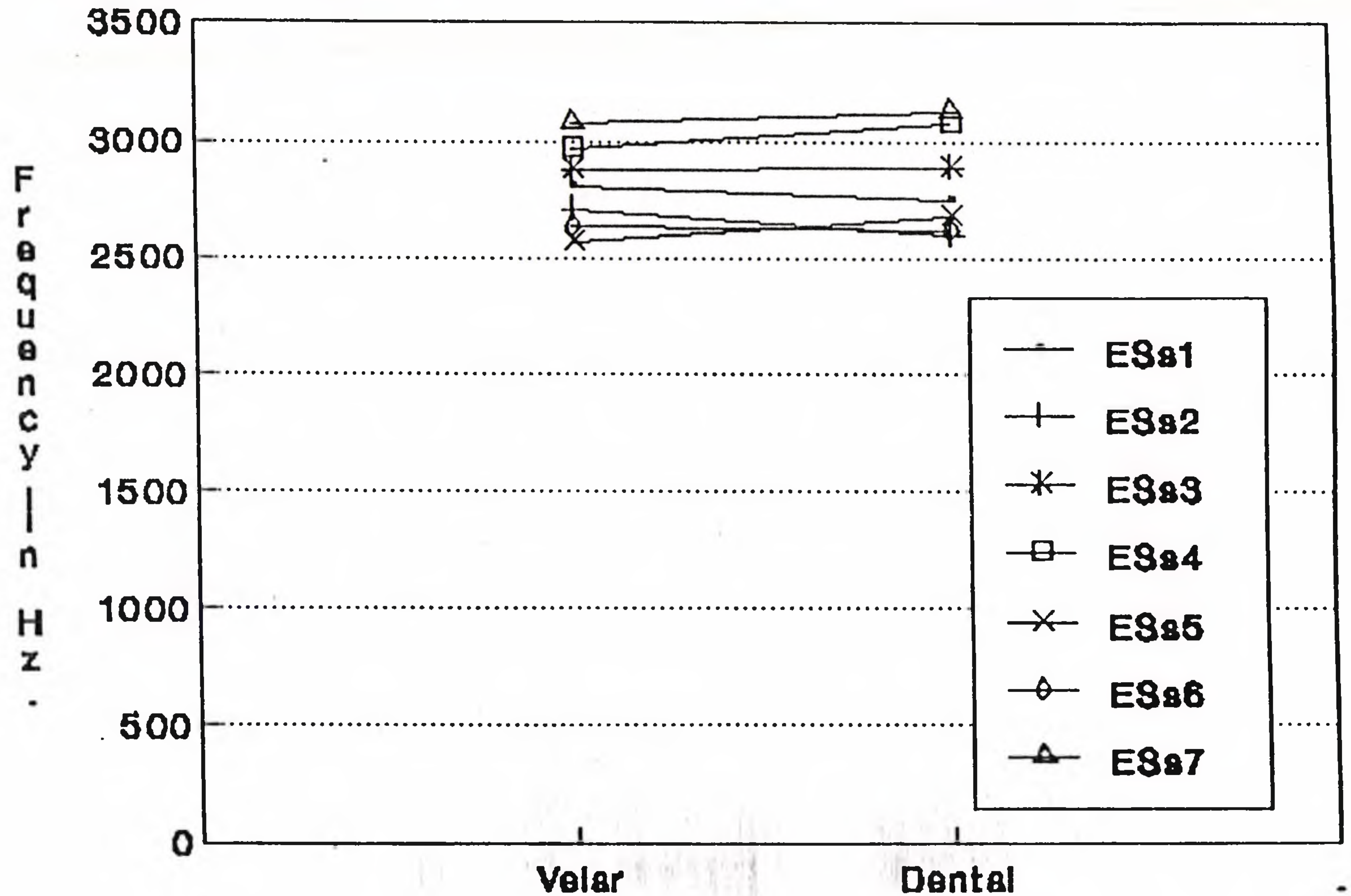


Fig. 4.23b:- Mean F2 related peak in LPC spectra of transient segment of velar and dental initial minimal pair spoken by each subject in Experimental group.

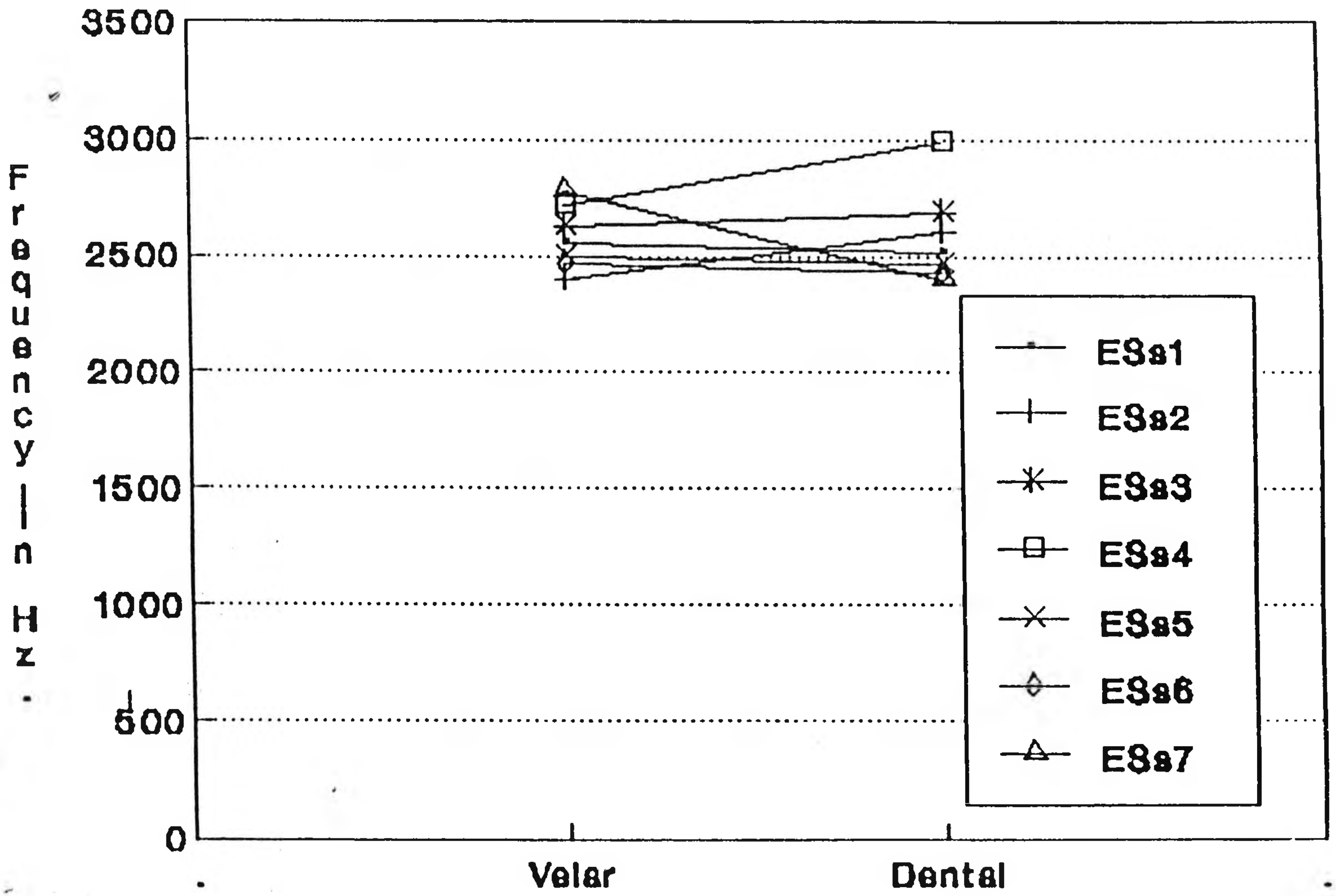


Fig. 4.2.4b:- Mean F2 related peak in LPC spectra of post-transient segment of velar and dental initial minimal pair spoken by each subject in Experimental group.

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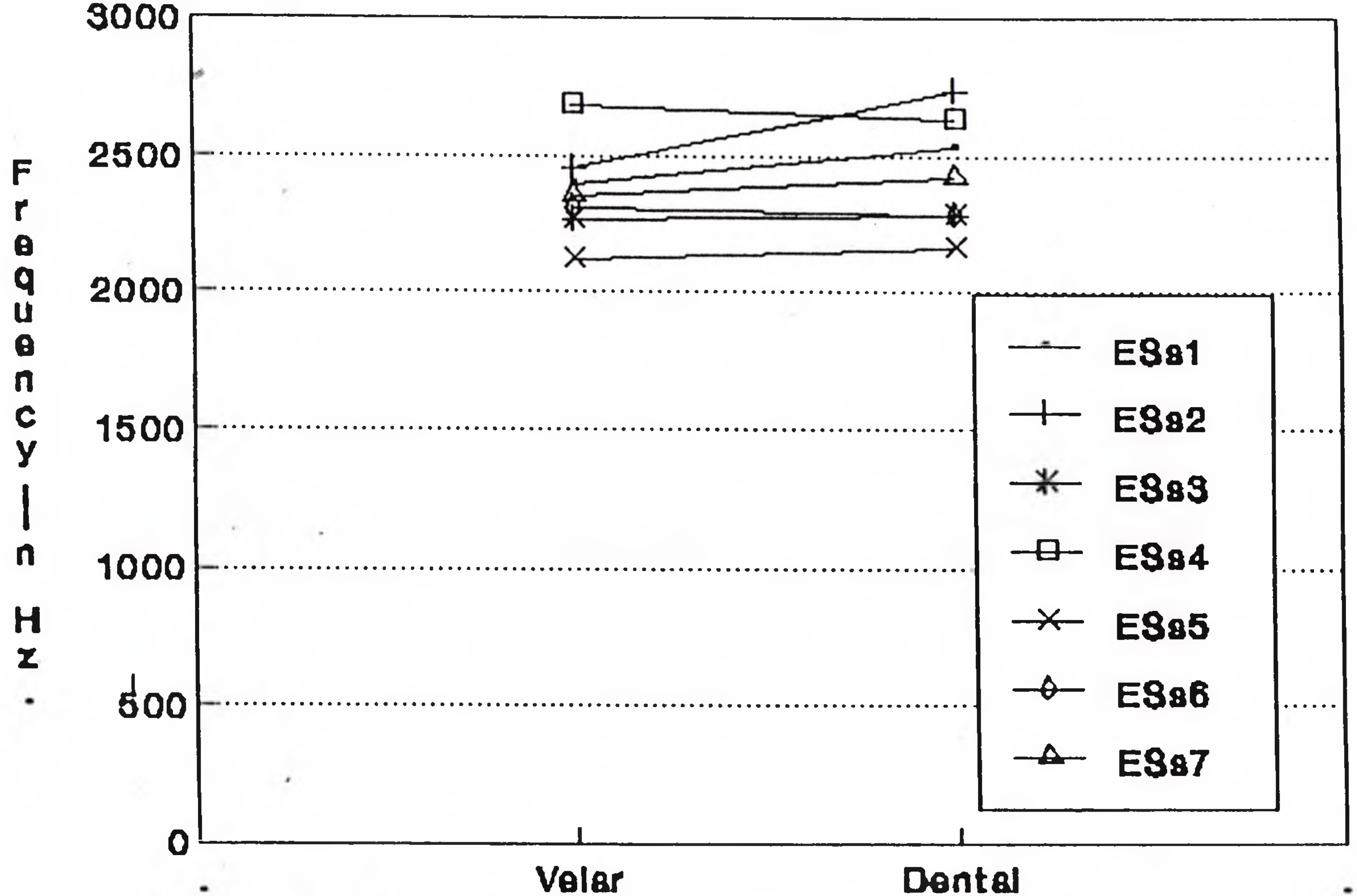

Fig. 4.2.5h:- Mean F2 related peak in LPC spectra of aspiration segment of velar and dental initial minimal pair spoken by each subject in Experimental group.

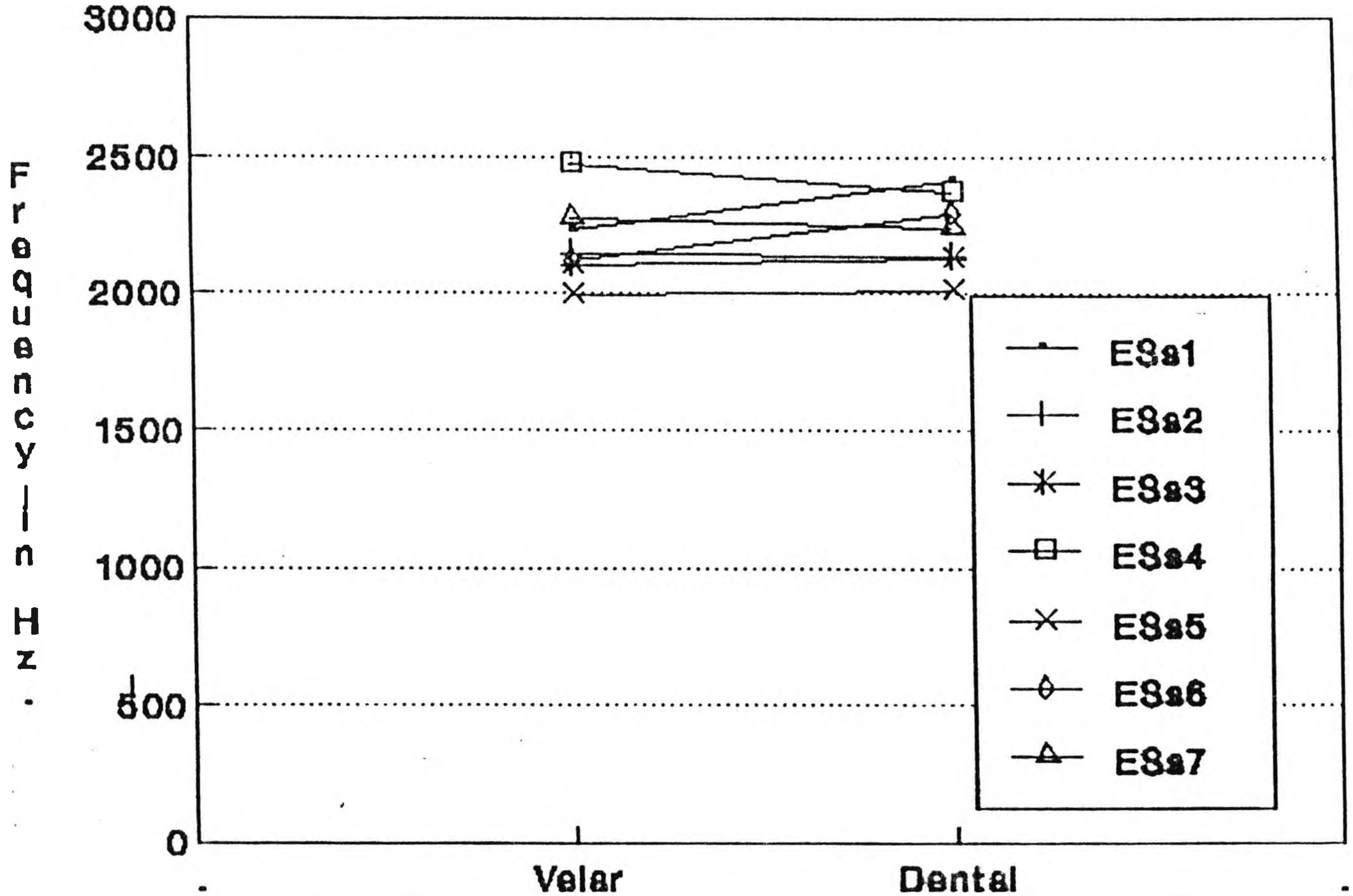

Fig. 4.1.6b- Mean F2 of vowel [a] in velar and dental initial minimal pair spoken by each subject in Experimental group.

Table 4.2.5b.:- The F-ratio and levels of significance for the **F2 related peak** for each of the segments and the sources of variation for the minimal pairs attempted by **subjects who front their velars.**

Analysis segment	sources of variation	df	F	P
	Subject	6	6.6	.000
Transient	[k]~[t̠] minimal pair	1	0.1	.814
	Subject X [k]~[t̠] minimal pairs	6	0.3	.934
	Subject	6	3.6	.002
Post-trans ient	[k]~[t̠] minimal pairs	1	0.01	.907
	Subject X [k]~[t̠] minimal pair	6	2.1	.064
	Subject	6	14.6	.000
Aspiration	[k]~[t̠] minimal pair	1	.386	.535
	Subject X [k]~[t̠] minimal pair.	6	0.7	.689
	Subject	6	11.5	.000
Vowel [a]	[k]~[t̠] minimal pair	1	1.3	.255
	Subject X [k]~[t̠] minimal pair	6	1.6	.151

iii) Comparison of F2-related peak in control group I & experimental group:-

The F2 related peaks for various segments were compared to those obtained for children in the two groups. The group means for the F2 related peak for the output of attempted minimal pairs for the two groups of subjects are given in Table 4.2.6, It is clear that the F2 related peak in all four segments was higher for the experimental group than those for dentals produced by subjects with no production errors.

<u>Tables 4.2.6:</u>- Mean and SD of **F2 related peak** in different segments of the velar and dental initial minimal pairs for subjects with and without velar fronting.

Segment of Analysis	/k^hali/				/$\underline{t}^h$ali/			
	Control Group I Mean	SD	Expt. Group Mean.	SD	Control Group I Mean	SD	Expt. Group Mean	SD
Transi-ent	1963	185	2804	335	2680	237	2818	411
Post-tr-ansient	1959	226	2578	349	2452	398	2584	521
Aspira-tion	1967	227	2371	244	2272	233	2392	248
Vowel [a]	1924	211	2194	227	2030	170	2230	227

Since there was no significant difference in the obtained mean F2 related peaks in all the segments, for the minimal pairs attempted by the velar fronting subjects, the question arose as to whether there would be a significant difference in these measures obtained for /$\underline{t}^h$alI/ spoken by children in control group I, and /k^h/~/$\underline{t}^h$/ production attempts by the seven subjects in the experimental group. Since all these outputs were largely heard as apical sounds, ANOVA was applied to ascertain whether the three groups of apical sounds differed in the F2 related peak measured in the four segments, that is, whether the apical sound was (i) the production output as a result of velar fronting, (ii) the dental aspirated sounds targeted by subjects who front velars, or (iii) the dental aspirated sounds spoken by control group I. In the ANOVA application this variable was referred to as the type of apical sound. In figure 4.2.7 are plotted the mean F2 related peak measures for the four segments for these three types of apical sounds. From the figure 4.2.7 it may be observed that the F2 related peak appears to be consistently higher for the experimental group than for the control group. The split-plot analysis of variance was applied to ascertain whether significant differences existed between the three groups of apical sounds mentioned above for the F2 related mean in the four segments. The obtained F-ratios are available for various sources of variation and are given in Table 4.2.7.

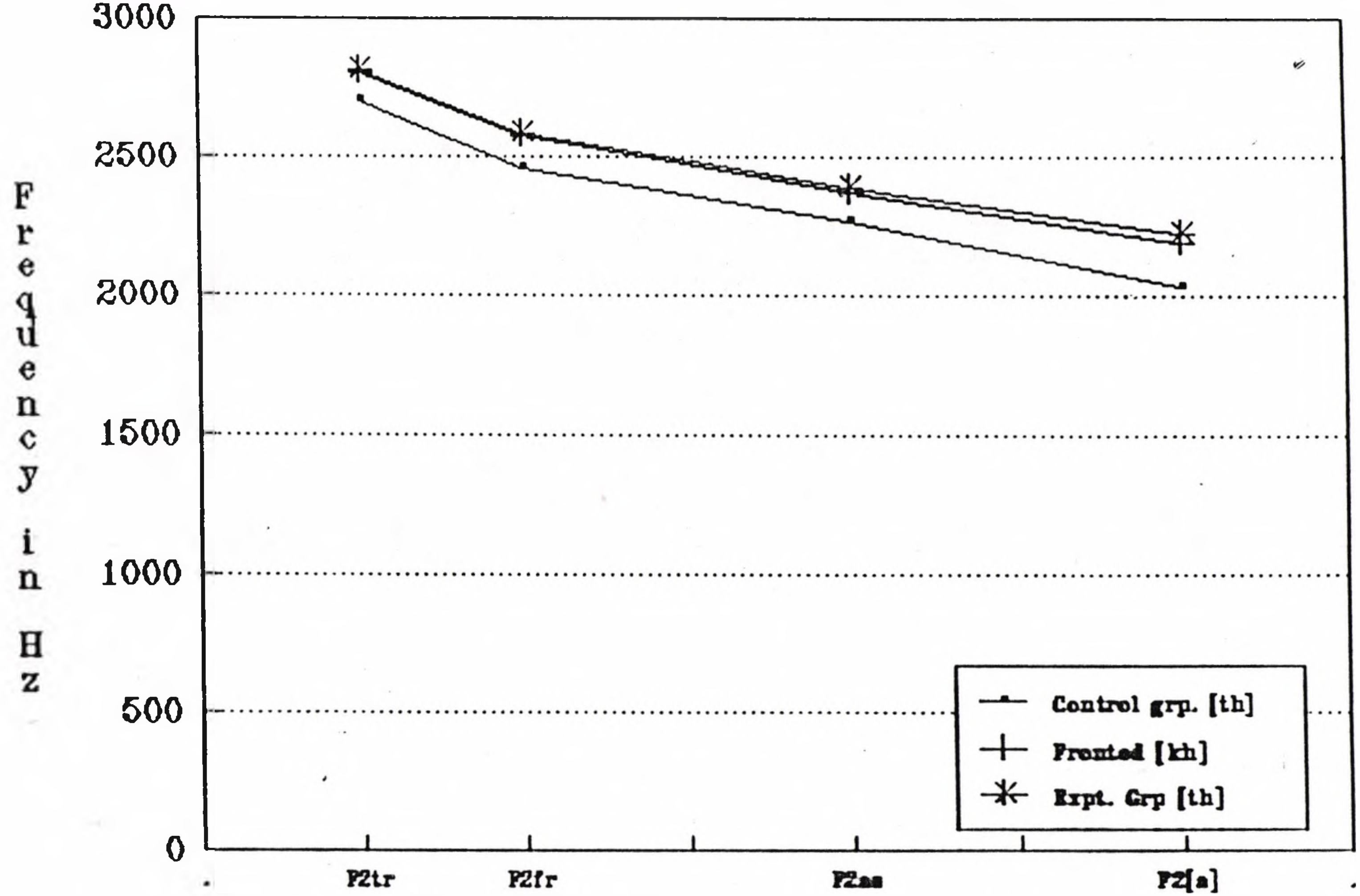

Fig.4.2.7:- Mean F2 related peak for various segments in the output tokens of /$\underline{t}^h$alI/ spoken by subjects in control group I and /$\underline{t}^h$alI/ and /k^halI/ attempted by subjects in experimental group.

Table 4.2.7:- The obtained F-ratio, degrees of freedom and significance level of obtained F-ratio, for the main (between group) effect of type of apical sound, the within group main effect of segment of measurement, and their interaction.

Sources of Variation	df	F	P
Type of apical Sound	2	6.3	.002
Error	187		
Segments of measurement	3	183.6	.000
Interaction (Type of apical sound x Segments)	6	0.4	.9
Error	561		

The obtained F-ratio indicates a significant main effect for type of apical sounds ($p<.002$). Application of Newman-Keuls (unplanned comparisons) indicated that the significant difference between the three groups of apical sound was mainly accounted for by the difference in F2 related peak for Control group I and the Experimental group ($p<.01$).

B. <u>**Spectral Shape of average LPC spectra of transient, post-transient and aspiration segment:-**</u>

The spectral shape of the velar produced by control group I generally had a strong mid frequency peak. Figures 4.2.8(a & b) and 4.2.9(a & b) show the mean relative intensity of F2 related peak, the lowest energy level

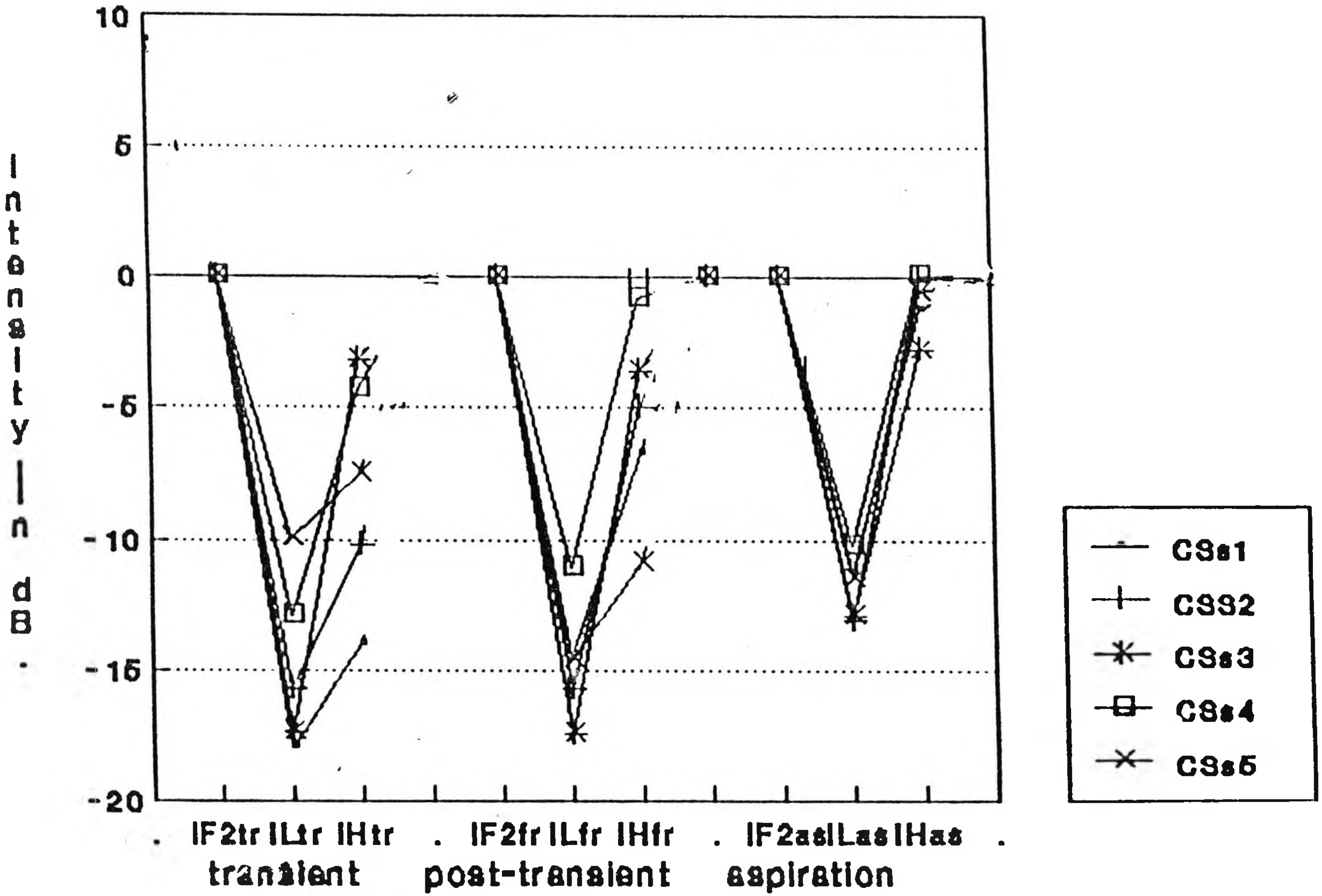

Fig. 4.28a:- The mean(dB) relative intensity of lowest dip between F2 related peak and 3 kHz and intensity of highest peak between 3 and 4 kHz in average LPC spectra of transient, post-transient and aspiration segment of /kʰalɪ/ spoken by each subject in Control group I.

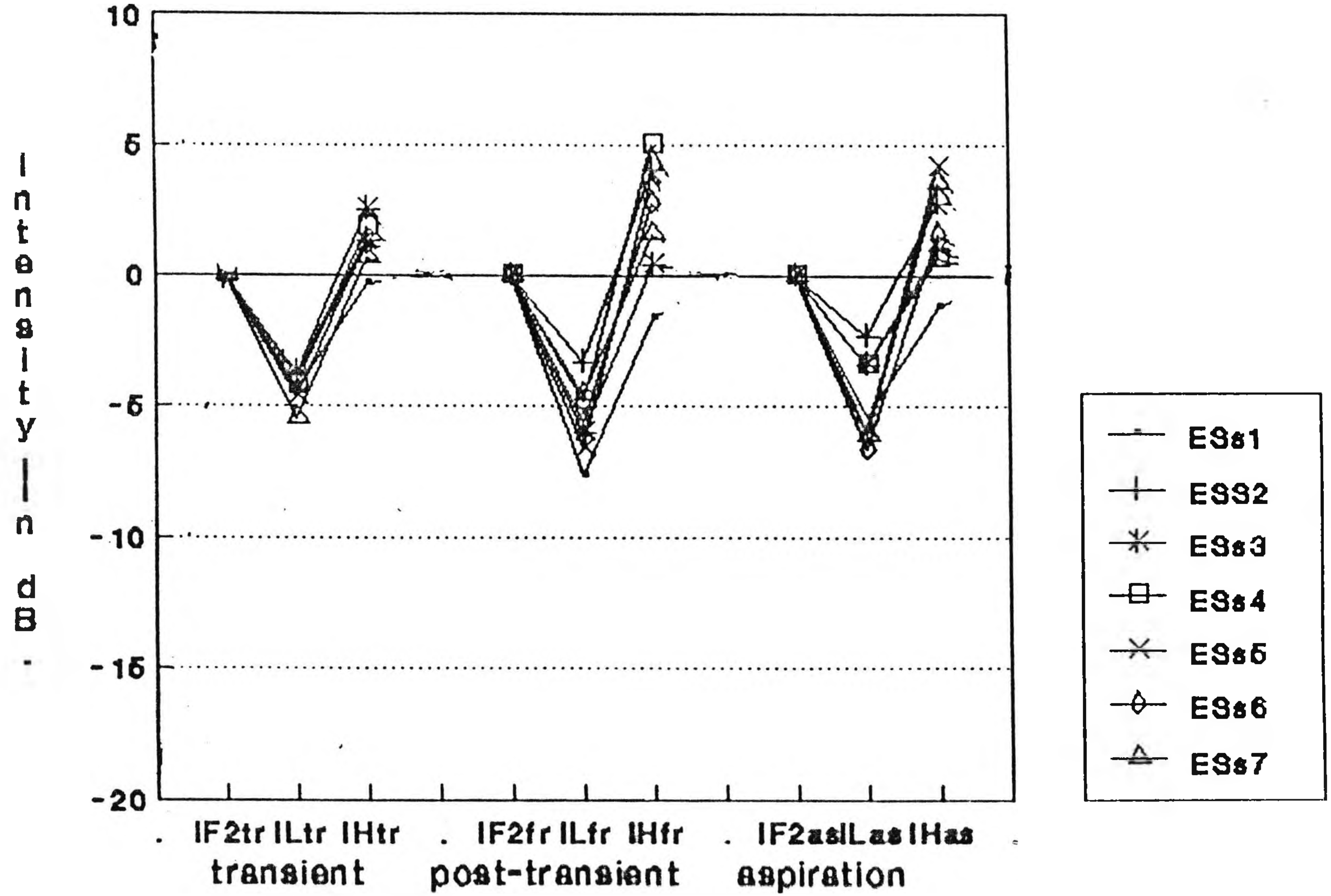

Fig. 4.2.8b:- The mean(dB) relative intensity of lowest dip between F2 related peak and 3 kHz and intensity of highest peak between 3 and 4 kHz in average LPC spectra of transient, post-transient and aspiration segment of /k^halI/ spoken by each subject in Experimental group.

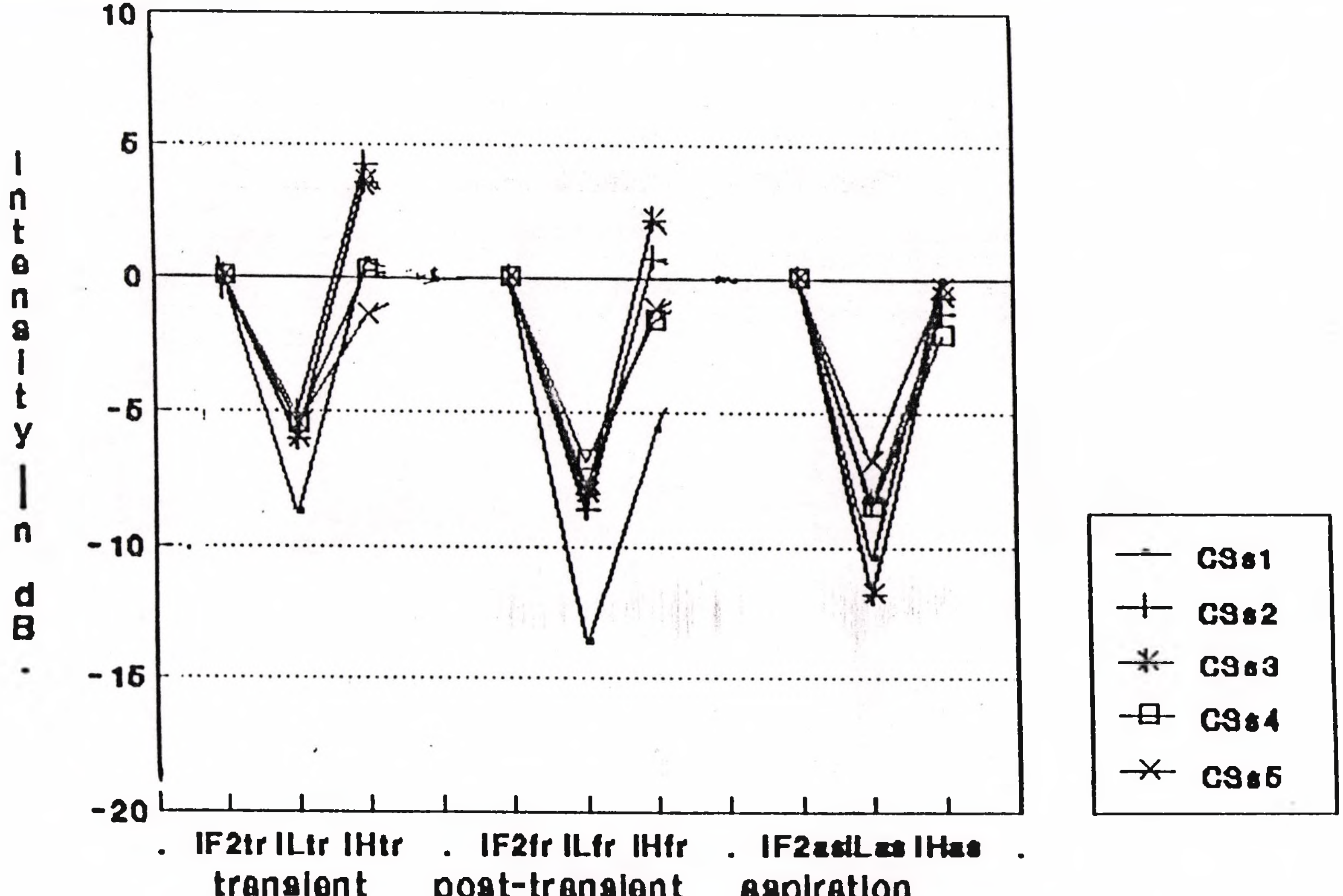

Fig. 4.2.9a: The mean(dB) relative intensity of lowest dip between F2 related peak and 3 kHz and intensity of highest peak between 3 and 4 kHz in average LPC spectra of transient, post-transient and aspiration segment of /t̪ʰal/ spoken by each subject in Control group I.

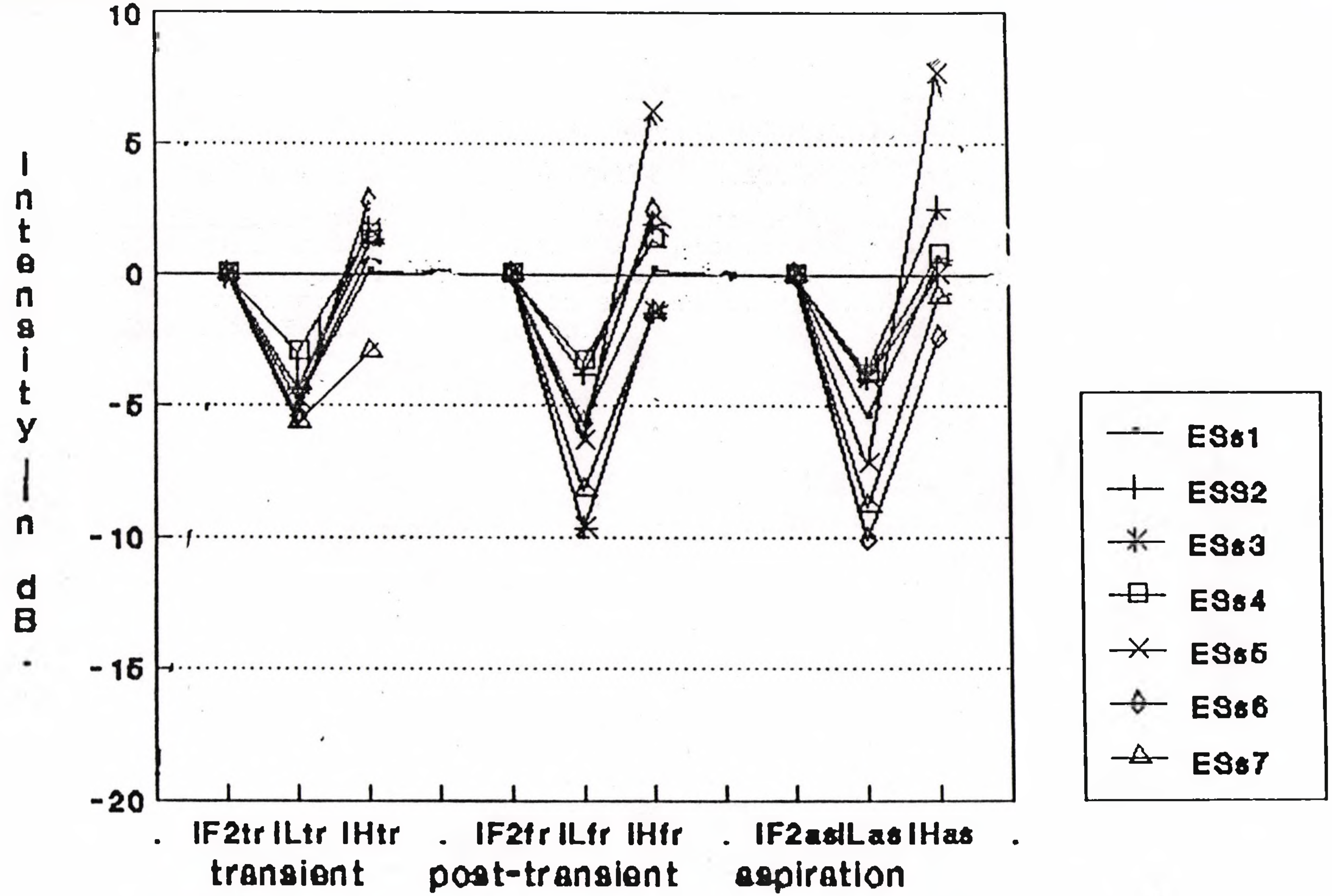

Fig.4.296 :- The mean(dB) relative intensity of lowest dip between F2 related peak and 3 kHz and intensity of highest peak between 3 and 4 kHz in average LPC spectra of transient, post-transient and aspiration segment of /t^halI/ spoken by each subject in Experimental group.

between the F2 related peak and 3kHz, and the highest energy peak between 3kHz and 4kHz for transient, post-transient and aspiration segment for /k^halI/ and /g^halI/ respectively for each of the groups. As intensity of `lowest energy level' (ILtr,ILfr and ILas) and intensity of `highest peak' (IHtr, IHfr and IHas) are measured in relation to the intensity of F2 related peak, the intensity IF2tr is assumed to be equal to zero in these graphs. Since the intensity axis of the frequency vs intensity spectra in the Sensimetrics is measured in relative dB, the values obtained were often negative (fig.4.2.1a, 4.2.1b, 4.2.1c, 4.2.1d, 4.2.1e, 4.2.1f, 4.2.1g,). When the intensity of the lowest energy level between the F2 related peak and 3 kHz was subtracted from intensity of the F2 related peak in the average spectra, a positive value was obtained which is reported in tables 4.2.8a, 4.2.10a, and 4.2.12a for control group and tables 4.2.8b, 4.2.10b, and 4.2.12b for the experimental group. The `highest peak' values tended to be negative if the peak between 3 and 4 kHz was greater than intensity of F2 related peak, (see table 4.2.9a & b, 4.2.11a & b, and 4.2.13a & b). In order to provide a correct visual relationship, the polarities were reversed while plotting the Figures 4.2.8(a & b) and 4.2.9(a & b).

i) Shape of average LPC spectra of the transient segment:-

1) Control group I:-

The mean and SD of ILtr value (the difference between intensity of the F2 related peak and intensity of lowest energy level between the F2 related peak and 3kHz in average LPC spectra of transient) and IHtr value (the difference between intensity of the F2 related peak and intensity of the highest energy peak between 3kHz and 4kHz in average LPC spectra of transient) in velar and dental initial minimal pair spoken by children with no production error are given in table 4.2.8a and 4.2.9a and for children with fronting of velars in table 4.2.8b and 4.2.9b . Often ILtr and IHtr for dentals could not be measured as the F2 related peak of the transient was close to or above 3kHz (Fig 4.2.1g).

In control group I, it was observed that for 96% velar tokens had ILtr greater than 8 compared to dentals which had only 26% (the value 8 has been chosen arbitrarily). In case of IHtr 90% of average LPC spectra of initial velar aspirate plosives had IHtr equal to or greater than zero. F2tr for velars was therefore the most prominent peak in the spectra. The F2 related peak was rarely the highest peak in the average LPC spectrum of dental transients. From Figure 4.2.8a it is clear that in the transient segments, the highest peak between 3kHz and 4kHz (IHtr) was greater than, or equal to the intensity of the F2 related peak in the case of subjects CSs2, CSs3, and CSs4. However the decrease in intensity between the F2 related peak and ILtr can be observed to be considerably more for velars than dentals spoken by control group I (Figure 4.2.8a and

4.2.9a). On examining the relative intensities of the F2 related peak in transients, ILtr, and IHtr in fig. 4.2.8a it appears that the average LPC spectra of transients of control group I, tend to resemble Stevens-Blumstein's description of alveolars and velars as rising and compact. Except for CSs5 all the mean IHtr were greater than or equal to the intensity of the F2 related peak in transient segment for dentals. However, all of the F2tr values were above 2500Hz for dental initial words spoken by CSs5 .

Table 4.2.8a: ILtr values for /k^{h}alI/ and /t̪^{h}alI/ spoken by normal children. (Generally ten values contributed to the mean per subject for each stimulus word. In case of measurement difficulties this number was less. The values enclosed in brackets indicate the number contributing to the mean.)

	/k^{h}alI/				/t̪^{h}alI/			
Ss .	Mean(n)	SD	Lowest	Highest	Mean(n)	SD	Lowest	Highest
CSs1.	17.9(10)	3.8	12	27	8.7(10)	2.8	5	12
CSs2.	15.7(10)	3.6	10	20	5.1(08)	2.8	1	9
CSs3.	17.3(10)	4.2	11	25	6.0(07)	4.0	1	11
CSs4.	12.9(10)	4.2	8	18	5.5(02)	2.1	5	6
CSs5.	9.9(10)	3.8	3	15	5.5(06)	1.9	4	9
Group	14.7(50)	4.8	3	27	6.5(33)	3.2	1	12

Table 4.2.9a: The mean (dB), SD, lowest and highest **IHtr values** for /k^halI/ and /$\underline{t}^h$alI/ spoken by normal children. (Generally ten values contributed to the mean per subject for each stimulus word. In case of measurement difficulties this number was less. The values enclosed in brackets indicate the number contributing to the mean.)

	/k^halI/				/$\underline{t}^h$alI/			
Ss.	Mean(n)	SD	Lowest	Highest	Mean(10)	SD	Lowest	Highest
CSs1.	14.0(10)	3.4	11	23	0.6(07)	2.5	-3	6
CSs2.	10.2(10)	5.6	0	18	-4.3(02)	3.4	-10	1
CSs3.	3.2(08)	7.7	-13	10	-3.6(04)	5.1	-9	5
CSs4.	4.3(08)	4.2	-2	10	-0.3(10)	.5	0	0
CSs5.	7.5(10)	3.9	1	13	1.4(09)	3.9	-5	8
Group	7.8(44)	6.4	-13	23	-1.4(32)	4.3	-10	8

2) **Experimental group:-**

The mean(dB), SD, lowest, and highest ILtr values and IHtr value for the minimal pair attempted by each subject in experimental group is given in table 4.2.8b and 4.2.9b.

Table 4.2.8b : The mean (dB), SD, lowest and highest **ILtr** values for /k^halI/ and /$\underline{t}^h$alI/ attempted by children who front their velars. (Generally ten values contributed to the mean per subject for each stimulus word. In case of measurement difficulties this number was less. The values enclosed in brackets indicate the number contributing to the mean.)

	/k^hali/				/$\underline{t}^h$ali/			
Ss .	Mean(n)	SD	Low	High	Mean(n)	SD	Low	High
ESs1.	4.4(05)	2.3	2	8	4.8 (05)	2.5	3	9
ESs2.	3.7(06)	1.6	2	6	4.4 (08)	3.6	1	12
ESs3.	3.7(06)	1.4	2	6	4.3 (04)	1.5	3	6
ESs4.	4.2(05)	3.3	1	9	3.0 (03)	1.7	2	5
ESs5.	4.7(07)	2.0	1	6	4.8 (08)	2.3	1	8
ESs6.	3.9(07)	.9	3	5	5.4 (08)	1.7	3	7
ESs7.	5.5(02)	2.1	4	7	5.7 (03)	4.0	2	5
Group	4.2(38)	1.9	1	9	4.7 (39)	2.5	1	12

The numbers enclosed in parenthesis indicate that almost half of the productions had high F2 related peaks which made it difficult to measure ILtr and IHtr values. From figure 4.2.8b and 4.2.9b it is clear that the intensity pattern reflected those patterns observed in dentals produced by subjects with no phonological disorders (Fig.4.2.8a). Only subject ESs7, while producing target dentals, displayed a pattern that resembled the intensity pattern reported for velars in subjects with no production errors. However, from table 4.2.8b and 4.2.9b it is obvious that 8/10 velars attempted by this subject had high F2 related peaks in the transient segment, that is, a mean of 3076 Hz which is typical of dentals.

The cut-off value of 8 was applied for separating velars and dentals attempted by the experimental group. Only one token of /k^{h}alI/ and two tokens of /t̪^{h}alI/ had values greater than 8. In case of IHtr values, it was observed that 38% of the velar and 43% of the dental tokens of experimental group had IHtr equal to or greater than zero.

Table 4.2.9b :- The mean (dB), SD, lowest, and highest **IHtr** values for /k^{h}alI/ and /t̪^{h}alI/ attempted by children who front their velars. (Generally ten values contributed to the mean per subject for each stimulus word. In case of measurement difficulties this number was less. The values enclosed in brackets indicate the number contributing to the mean.)

	/k^{h}ali/				/t̪^{h}ali/			
Ss .	Mean(n)	SD	Low	High	Mean(n)	SD	Low	High
ESs1.	0.3(10)	5.5	-8	7	-.1(10)	5.2	-10	5
ESs2.	-1.4(10)	2.5	-5	3	-1.2(10)	3.4	-6	5
ESs3.	-2.6(08)	4.0	-7	5	-1.7(09)	4.2	-9	3
ESs4.	-1.9(07)	2.9	-5	3	-1.5(06)	3.2	-6	2
ESs5.	-1.3(10)	3.4	-8	5	-.7(09)	3.1	-5	5
ESs6.	-1.2(10)	3.8	-7	6	-2.8(08)	2.9	-6	3
ESs7.	-.7(06)	3.5	-5	4	3.0(10)	3.0	-2	6
Group	-1.2(61)	3.7	-8	7	-.6(62)	4.0	-10	6

ii) Shape of average LPC spectra of post-transient segment:- 1) Control group I:-

The mean(dB) and SD, lowest, and highest ILfr value (the difference between intensity of the F2 related peak and the lowest energy level between the F2 related peak and 3kHz in average LPC spectra of post-transient segment) and IHfr value (the difference between intensity of the F2 related peak and intensity the highest energy peak between 3kHz and 4kHz in average LPC spectra of post-transient segment) are given in table 4.2.10a and 4.2.11a. It was observed that although 94% of velars had ILfr equal to or greater than 8, there were 56% of dentals with ILfr equal to or greater than 8. In case of IHfr values, 76% of velars had IHfr equal to or less than zero for the segment compared to 52% of dentals (Fig.4.2.8a and 4.2.9a).

Table 4.2.10a: ILfr values The mean (dB), SD, lowest and highest **ILfr values** for /k^{h}alI/ and /$\underline{t}^h$alI/ spoken by normal children. (Generally ten values contributed to the mean per subject for each stimulus word. In case of measurement difficulties this number was less. The values enclosed in brackets indicate the number contributing to the mean.)

	/k^{h}alI/				/$\underline{t}^h$alI/			
Ss	Mean(n)	SD	Lowest	Highest	Mean(n)	SD	Lowest	Highest
CSs1.	14.4(10)	6.5	4	19	13.7(10)	4.1	8	19
CSs2.	15.7(10)	4.7	10	25	8.6(09)	4.3	3	17
CSs3.	17.4(10)	3.9	12	26	8.0(10)	4.5	2	14
CSs4.	11.0(10)	4.0	6	17	6.8(06)	2.3	3	9
CSs5.	14.6(10)	3.7	9	20	7.6(08)	4.7	1	13
Group	14.6(50)	4.9	4	25	8.9(43)	4.6	1	19

Table 4.2.11a: The mean(dB), SD, lowest and highest **IHfr values** for $/k^halI/$ and $/\underline{t}^halI/$ spoken by normal children. (Generally ten values contributed to the mean. In case of measurement difficulties this number was less. The values enclosed in brackets indicate the number contributing to the mean.)

Ss	$/k^halI/$ Mean(n)	SD	Low	High	$/\underline{t}^halI/$ Mean(n)	SD	Low	High
CSs1.	6.7(10)	6.1	-2	18	5.7(10)	4.6	-2	11
CSs2.	5.0(10)	8.2	-11	16	-0.8(10)	4.4	-8	7
CSs3.	3.6(10)	6.4	-5	15	-2.2(10)	4.7	-9	7
CSs4.	0.8(10)	4.5	-10	6	1.6(08)	3.7	-4	9
CSs5.	10.9(10)	5.6	1	21	1.2(10)	7.0	-11	14
Group	5.4(50)	6.9	-11	21	1.1(48)	5.6	-11	14

2) Experimental group:-

The mean (dB), SD, lowest, and highest ILfr and IHfr values for the minimal pair spoken by the subjects in the experimental group are given in table 4.2.10a and 4.2.11a. From figure 4.2.8b and 4.2.9b, it is clear that the pattern largely reflects those obtained for dentals produced by subjects with no production errors. Further, on comparing transient and post-transient segments in figure 4.2.8b and 4.2.9b, ILfr level is seen to increase, more so for dentals than for velars. However, the systematic decrease in relative intensity of the highest peak between 3 and 4 kHz observed in dentals of control group I is not observed in either $/k^halI/$ or $/\underline{t}^halI/$ attempted by the experimental group (Figure 4.2.9a, 4.2.8b and 4.2.9b). Greater variability in the post-transient segment for ILfr value than in the transient segment is observed for /$\underline{t}^h$alI/ compared to /k^halI/ (figure 4.2.8b and 4.2.9b).

Table 4.2.10b:- Mean, SD, lowest and highest **ILfr** values for /k^halI/ and /$\underline{t}^h$alI/ attempted by children who front their velars. (Generally ten values contributed to the mean per subject for each stimulus word. In case of measurement difficulties this number was less. The values enclosed in brackets indicate the number contributing to the mean.)

	/k^hali/				/$\underline{t}^h$ali/			
Ss .	Mean(n)	SD	Low	High	Mean(n)	SD	Low	High
ESs1.	7.6(07)	3.2	4	11	5.8(09)	3.1	2	11
ESs2.	3.3(08)	2.7	-1	7	3.8(06)	2.7	1	7
ESs3.	6.0(07)	2.7	3	10	9.7(07)	4.2	3	14
ESs4.	4.8(05)	3.0	1	9	3.3(03)	.6	3	4
ESs5.	6.6(09)	2.8	2	12	6.4(08)	3.1	3	13
ESs6.	5.7(09)	2.9	3	11	9.8(10)	4.5	4	17
ESs7.	4.6(05)	2.3	2	8	8.2(10)	2.8	4	12
Group	5.6(50)	3.0	-1	12	7.2(53)	3.9	1	17

Table 4.2.11b:- The mean (dB), SD, lowest and highest **IHfr** values for /k^halI/ and /$\underline{t}^h$alI/ attempted by children who front their velars. (Generally ten values contributed to the mean per subject for each stimulus word. In case of measurement difficulties this number was less. The values enclosed in brackets indicate the number contributing to the mean.)

	/k^hali/				/$\underline{t}^h$ali/			
Ss	Mean(n)	SD	Low	High	Mean(n)	SD	Low	High
ESs1.	1.6(10)	3.6	-4	8	-0.1(09)	5.2	-10	7
ESs2.	-4.1(10)	5.0	-10	8	-2.0(09)	3.4	-6	5
ESs3.	-.4(10)	3.7	-7	5	1.4(08)	3.8	-4	7
ESs4.	-5.0(08)	5.2	-13	3	-1.1(07)	3.5	-6	3
ESs5.	-3.8(10)	4.7	-12	4	-6.2(09)	7.1	-16	5
ESs6.	-2.8(10)	3.0	-7	2	-2.5(10)	6.6	-15	6
ESs7.	-1.7(09)	7.9	-15	10	1.4(10)	3.5	-2	7
Group	-2.3(67)	5.1	-15	10	-1.3(62)	5.4	-16	7

The cut-off value of 8 was applied for separating velars and dentals attempted by the experimental group. Only 20% token of /k^halI/ and 30% of /$\underline{t}^h$alI/ tokens had ILfr values greater than 8. In case of IHfr values, it was observed that 30% of the velar and 50% of dental tokens of the experimental group had IHfr equal to or greater than zero.

iii) Shape of average LPC spectra of aspiration segment:-

1) Control group:-

The mean, SD, lowest and highest ILas value (the difference between intensity of F2 related peak and the lowest energy level between F2 related peak and 3kHz in average

LPC spectra of aspiration) and IHas value (the difference between intensity of the F2 related peak and intensity the highest energy peak between 3kHz and 4kHz in average LPC spectra of aspiration) of /k^h/~/$\underline{t}^h$/ minimal pairs spoken by children with no production error are given in table 4.2.12a and 4.2.13a. From Figure 4.2.8a and 4.2.9a it is clear that in the aspiration segment the energy distribution for both velars and dentals becomes very similar. It was observed that 96% of velars and 66% of dentals had ILas value greater than or equal to 8. In the case of IHas, 48% of velars and 42% of dentals had IHas values equal to or greater than the intensity of the F2 related peak in aspiration.

Table 4.2.12a:- The mean(dB), SD, lowest and highest **ILas values** for /k^halI/ and /$\underline{t}^h$alI/ spoken by normal children.

	/k^halI/				/$\underline{t}^h$alI/			
Ss	Mean	SD	Lowest	Highest	Mean	SD	Lowest	Highest
CSs1.	11.2	3.0	7	17	10.4	3.3	7	15
CSs2.	13.1	4.4	8	21	8.2	2.6	5	13
CSs3.	12.9	3.2	8	16	11.8	3.2	8	17
CSs4.	10.2	1.8	8	14	8.5	1.4	7	11
CSs5.	11.5	3.5	5	18	6.8	3.9	1	13
Group	11.8	3.3	5	21	9.2	3.4	1	17

Table 4.2.13a: The mean(dB), SD, lowest and highest **IHas values** for /k^halI/ and /$\underline{t}^h$alI/ spoken by normal children.

	/k^halI/				/$\underline{t}^h$alI/			
Ss .	Mean	SD	Lowest	Highest	Mean	SD	Lowest	Highest
CSs1.	1.3	2.8	-2	6	0.8	3.2	-4	5
CSs2.	0.1	3.4	-5	5	1.3	6.1	-7	13
CSs3.	2.8	4.1	-5	7	0.7	3.6	-4	7
CSs4.	-1.1	5.9	-8	15	-0.1	7.0	-8	8
CSs5.	0.6	5.2	-8	10	0.3	5.1	-8	8
Group	0.9	4.7	-8	15	0.5	4.6	-8	13

The cut-off value of 8 was applied for separating velars and dentals attempted by the experimental group. Only 11% of /k^halI/ and 21% of /$\underline{t}^h$alI/ tokens had ILas values greater than 8. In case of IHas values, it was observed that 39% of the velar and 49% of the dental tokens of the experimental group had IHtr values equal to or greater than zero.

2) **Experimental group:-**

The mean(dB), SD, lowest and highest **ILas** and **IHas** for the minimal pair spoken by the subjects in the experimental group are given in table 4.2.12b and 4.2.13b. From figure 4.2.8b, and 4.2.9b, it appears that there is a difference in the change in nature of the intensity pattern from the transient segment to the aspiration segment for velars but not for dentals. Furthermore, the intensity pattern appears to be much more variable from subject to subject for velars than for dentals.

Table 4.2.12b:- The mean (dB), lowest and highest **ILas** values for /k^halI/ and /$\underline{t}^h$alI/ attempted by children who front their velars. (Generally ten values contributed to the mean per subject for each stimulus word. In case of measurement difficulties this number was less. The values enclosed in brackets indicate the number contributing to the mean.)

	/k^hali/				/$\underline{t}^h$ali/			
Ss	Mean(n)	SD	Low	High	Mean(n)	SD	Low	High
ESs1.	5.4(10)	2.5	1	9	5.4(09)	2.5	1	9
ESs2.	2.3(09)	2.9	-4	7	3.6(09)	1.8	1	6
ESs3.	3.4(09)	3.6	-5	7	4.0(07)	1.4	3	6
ESs4.	3.4(07)	.5	3	4	3.8(04)	.5	3	4
ESs5.	5.9(10)	1.3	4	8	7.2(08)	2.0	3	10
ESs6.	6.6(09)	4.0	2	14	10.1(10)	.8	1	11
ESs7.	6.1(08)	3.0	-5	14	8.9(08)	2.9	1	11
Group	4.8(62)	3.1	-5	14	6.3(55)	3.1	1	11

Table 4.2.13b:- The mean (dB), lowest and highest **IHas** values for /k^halI/ and /$\underline{t}^h$alI/ attempted by children who front their velars. (Generally ten values contributed to the mean per subject for each stimulus word. In case of measurement difficulties this number was less. The values enclosed in brackets indicate the number contributing to the mean.)

	/^{k}hali/				/$\underline{t}^h$ali/			
Ss	Mean(n)	SD	Low	High	Mean(n)	SD	Low	High
ESs1.	1.2(10)	3.9	-5	7	-0.5(08)	3.3	-6	3
ESs2.	-2.8(09)	5.5	-13	7	-2.6(10)	2.7	-7	1
ESs3.	-1.0(09)	5.1	-10	4	.0(07)	3.3	-3	6
ESs4.	-.7(09)	3.5	-8	4	-0.8(08)	3.3	-6	4
ESs5.	-4.2(10)	3.7	-8	5	-7.7(09)	2.1	-11	4
ESs6.	-1.6(09)	3.2	-6	2	2.4(08)	2.9	-1	8
ESs7.	-3.6(08)	3.7	-9	3	.8(08)	4.4	-8	6
Group	-1.8(64)	4.4	-13	7	-1.4(58)	4.3	-11	8

C) <u>Time related measures</u>:-

The time related measures examined in this study are duration of transient, aspiration, following vowel, entire word, and voice onset time.

i) <u>Duration of Transient and Aspiration segment</u>:-

Only about half of velars and one-third of dentals spoken by control group, had an identifiable frication segment. As the "frication" component of stop plosives was not consistently identifiable in child data, separate duration analysis was not done. Thus duration of the aspiration segment (Das) was calculated from the end of transient segment to beginning of periodicity.

1) <u>Control group I</u> :-

In table 4.2.14a and 4.2.15a are presented the mean and SD of transient (Dtr) and aspiration (Das) duration respectively.

<u>Table 4.2.14a:</u>- The mean and SD of **transient duration(Dtr)** of initial velar and dental aspirated plosives spoken by subjects with no production errors.

	/k^halI/		/$\underline{t}^h$alI/	
Ss	Mean(ms).	SD	Mean(ms).	SD.
CSs1.	7.5	2.5	5.5	2.2
CSs2.	8.9	2.4	7.6	2.2
CSs3.	9.6	2.0	10.0	2.3
CSs4.	8.6	2.6	7.4	1.7
CSs5.	9.3	2.3	8.8	2.6
Group	8.8	3.4	7.9	2.6

Table 4.2.15a:- The mean and SD of **aspiration duration (Das)** of initial velar and dental aspirated plosives spoken by subjects with no production errors.

Ss	$/k^{h}alI/$ Mean(ms).	SD	$/\underline{t}^{h}alI/$ Mean(ms).	SD.
CSs1.	83.9	13.4	75.6	11.0
CSs2.	55.7	20.0	40.7	16.0
CSs3.	96.5	29.1	40.7	16.0
CSs4.	75.0	23.1	90.2	28.2
CSs5.	58.1	16.6	46.8	20.0
Group	73.8	25.6	58.8	27.5

The two factor completely randomised analysis of variance was applied to the data and the results are available in table 4.2.16a. The resultant F-ratio indicates that there are significant differences in transient duration but not in aspiration duration for the two sounds. The lack of interaction indicates that the differences in Dtr for the minimal pair were similar for individual subjects. From Fig.4.2.10a it is clear that CSs1, CSs2, CSs4, and CSs5 had consistently longer Dtr for velars compared to dentals, while for CSs3 the reverse was true. Fig. 4.2.11a indicates that CSs1 and CSs4 have dramatically different Das for velar and dentals when compared to the other three subjects.

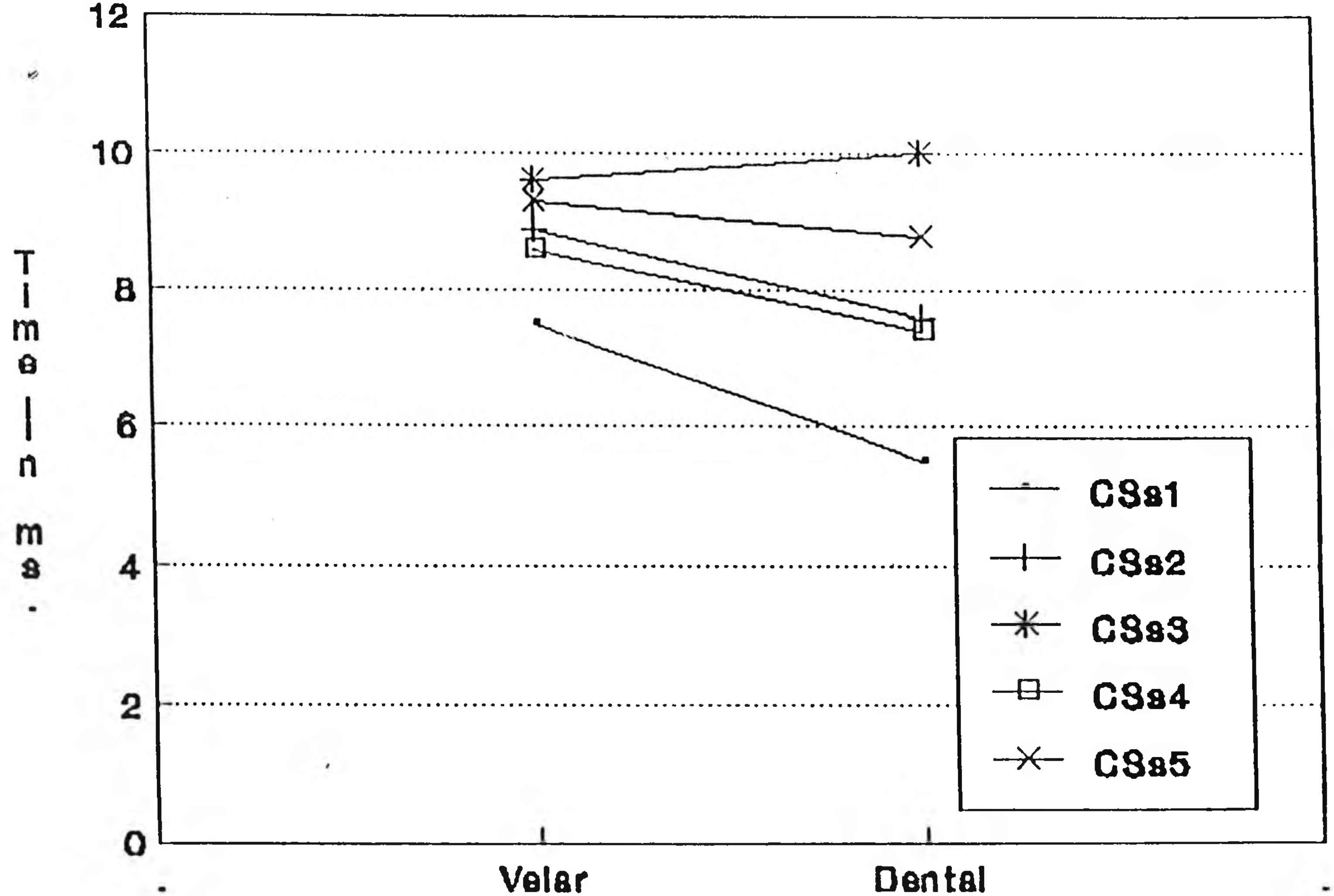

Fig. 4.2.10a:- The mean transient duration (Dtr) of initial velar and dental aspirated plosives spoken by each subject in Control group I.

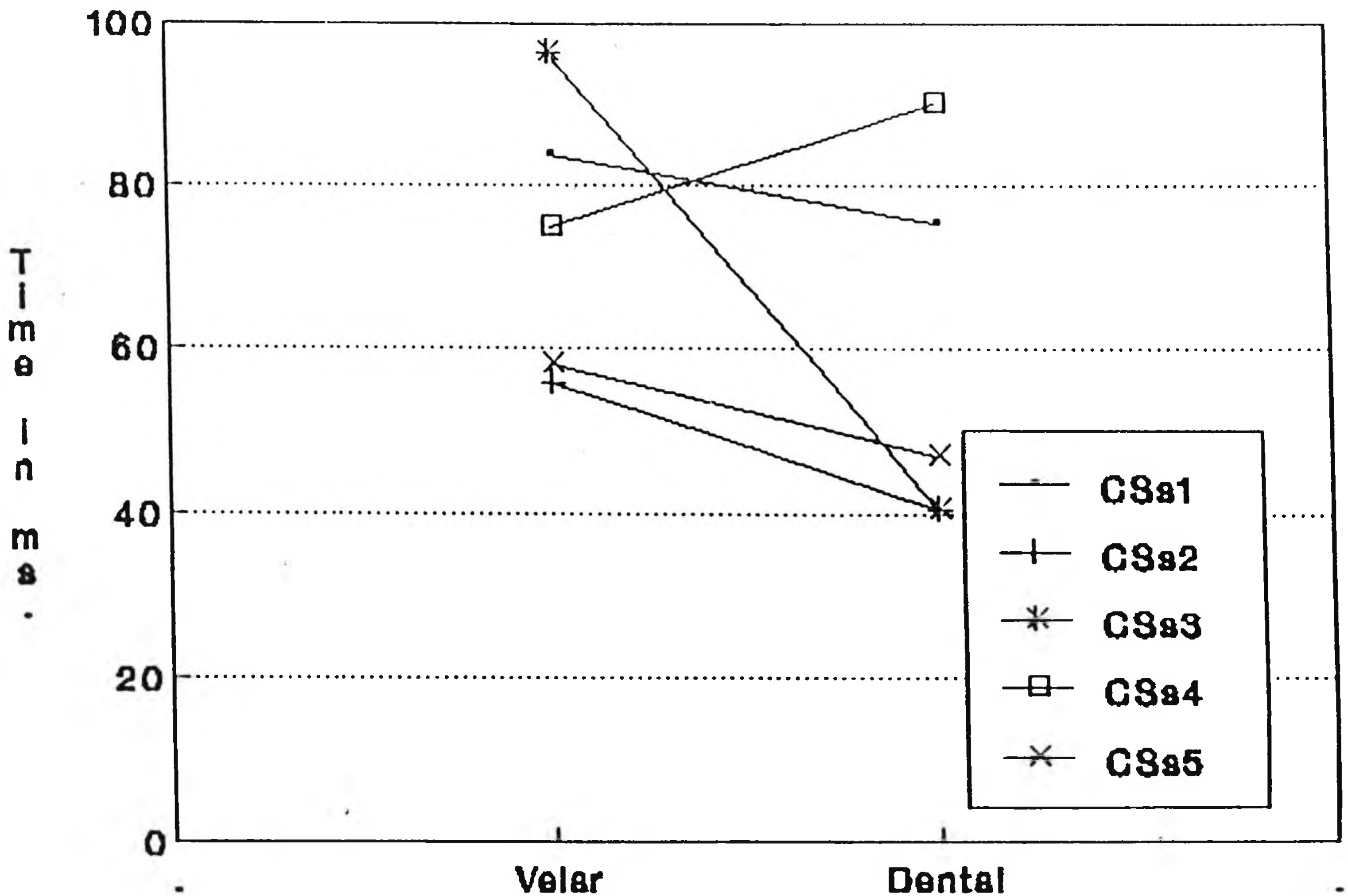

Fig. 4.2.11a:- The mean aspiration duration (Das) of initial velar and dental aspirated plosives spoken by each subject in Control group I.

Table 4.2.16a:- The F-value and levels of significance for Duration of Transient, and Aspiration segment for the sources of variation for control group I.

Variable	sources of variation	df	F	P
Duration of Transient	Subject	4	5.92	.000
	Speech sound [k] & [t̠]	1	4.1	.046
	Subject X Speech sound [k] & [t̠]	4	.8	.531
Duration of Aspiration	Subject	4	22.7	.000
	Speech sound [k] & [t̠]	1	1.01	.318
	Subject X Speech sound [k] & [t̠]	4	.19	.941

Transient durations have not been routinely reported by previous researchers. Fant (1968) observed that the duration of the transient phase is of the order of 2-30 ms and generally less than 10ms. He also stated that velars have transients longer than any other stops (Fant, 1973). The present findings confirm that this is also true in the case of children producing aspirated voiceless dental and velar plosives, the mean difference being just 0.9 ms. There has been reference to double transients in plosives (Hewlett, 1988). This was observed in only one velar production of one subject in the present data.

2) Experimental group:-

In table 4.2.14b and 4.2.15b are presented the mean and SD of transient and aspiration segment duration respectively for velar fronting subjects. The graph of the mean transient duration for the minimal pairs for each subject is given in figure 4.2.10b. The F-ratio obtained from the completely randomised ANOVA indicates that the subjects differed significantly for this measure (Table 4.2.16b). However, the obtained F-ratio failed to reach significance for the difference of Dtr in minimal pairs attempted by subjects who front velars. Furthermore, no significant interaction effects were obtained (Table 4.2.16b).

Table 4.2.14b:- The mean and SD of **transient duration (Dtr)** of initial velar and dental aspirated plosives attempted by subjects who front their velars.

	/kʰali/		/t̪ʰali/	
Ss	Mean(ms)	SD	Mean(ms)	SD
ESs1.	9.1	1.5	9.4	1.6
ESs2.	15.9	9.5	18.0	7.7
ESs3.	11.1	2.7	10.9	3.4
ESs4.	11.3	2.7	10.3	2.2
ESs5.	12.5	3.8	11.3	2.8
ESs6.	13.1	3.9	13.2	2.8
ESs7.	13.9	4.7	12.8	3.1
Group	12.4	5.0	12.3	4.6

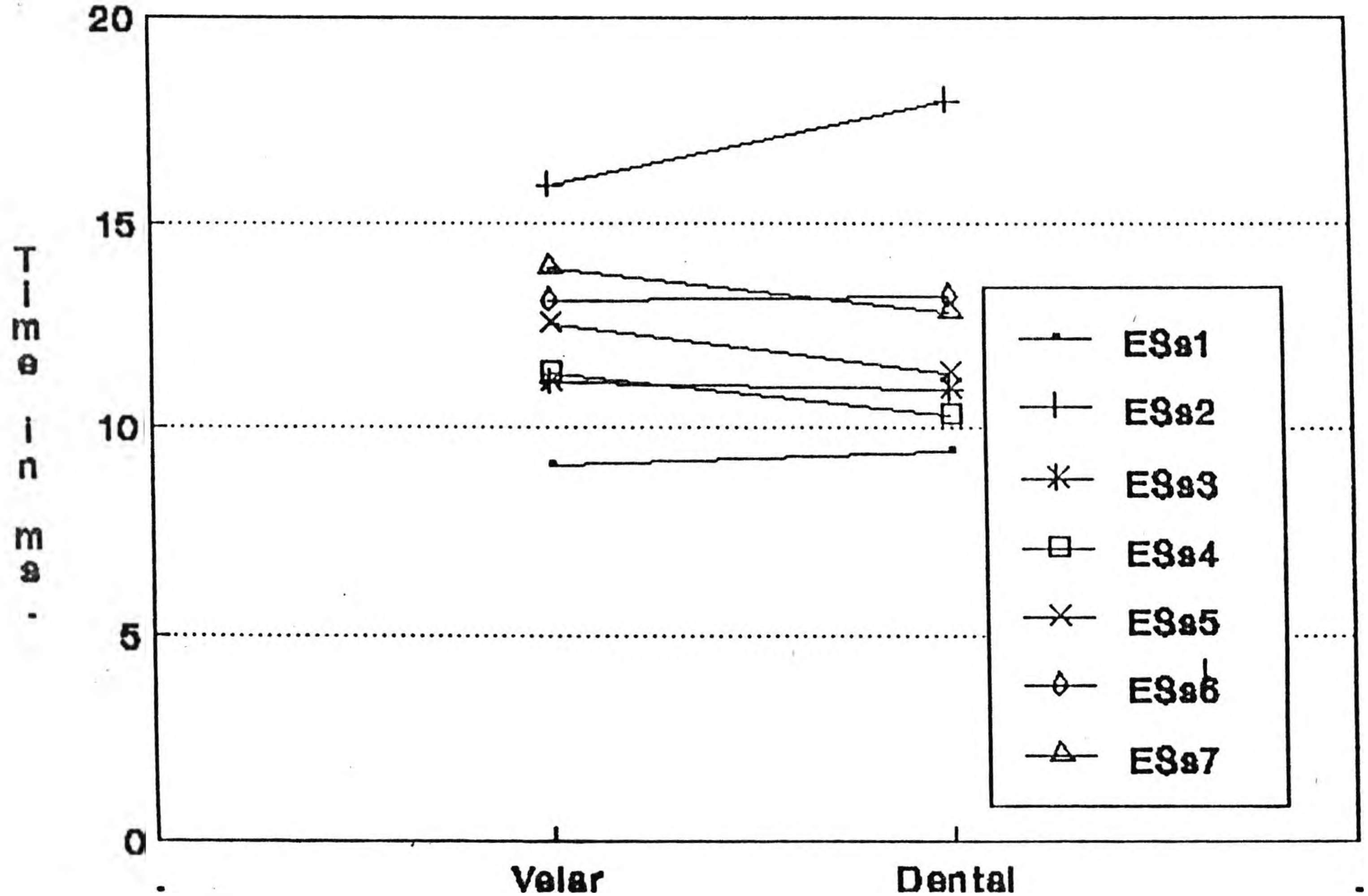

Fig.4.2.10b:- The mean transient duration (Dtr) of initial velar and dental aspirated plosives spoken by each subject in Experimental group.

Table 4.2.15b:- The mean and SD of **aspiration duration (Das)** of initial velar and dental aspirated plosives attempted by subjects who front their velars.

Ss	/k^hali/ Mean(ms)	SD	/$\underline{t}^h$ali/ Mean(ms)	SD
ESs1.	40.7	7.4	40.4	11.1
ESs2.	71.2	26.6	82.9	20.6
ESs3.	59.7	19.0	34.9	20.0
ESs4.	52.3	22.3	89.1	19.2
ESs5.	106.8	8.5	110.1	35.3
ESs6.	36.3	21.7	37.6	15.4
ESs7.	61.3	18.9	54.5	26.4
Group	61.2	28.8	64.2	34.6

From the graph of mean aspiration duration for the minimal pair attempted by each subject in figure 4.2.11b, it can be seen that there is considerable variability in this measure among subjects. The F-ratio confirms that the subjects differed significantly in this measure (Table 4.2.16b). Differences in the mean aspiration duration for velars and dentals failed to reach .05 level of significance. There was, however, a significant interaction effect ($p<.001$). The graph in figure 4.2.11b indicates that ESs3 and ESs4 had a greater mean difference in aspiration duration for the two sounds than the other subjects. Application of Scheffee's test revealed that both the subjects maintained significantly different aspiration duration for the two sounds beyond the .01 level of significance.

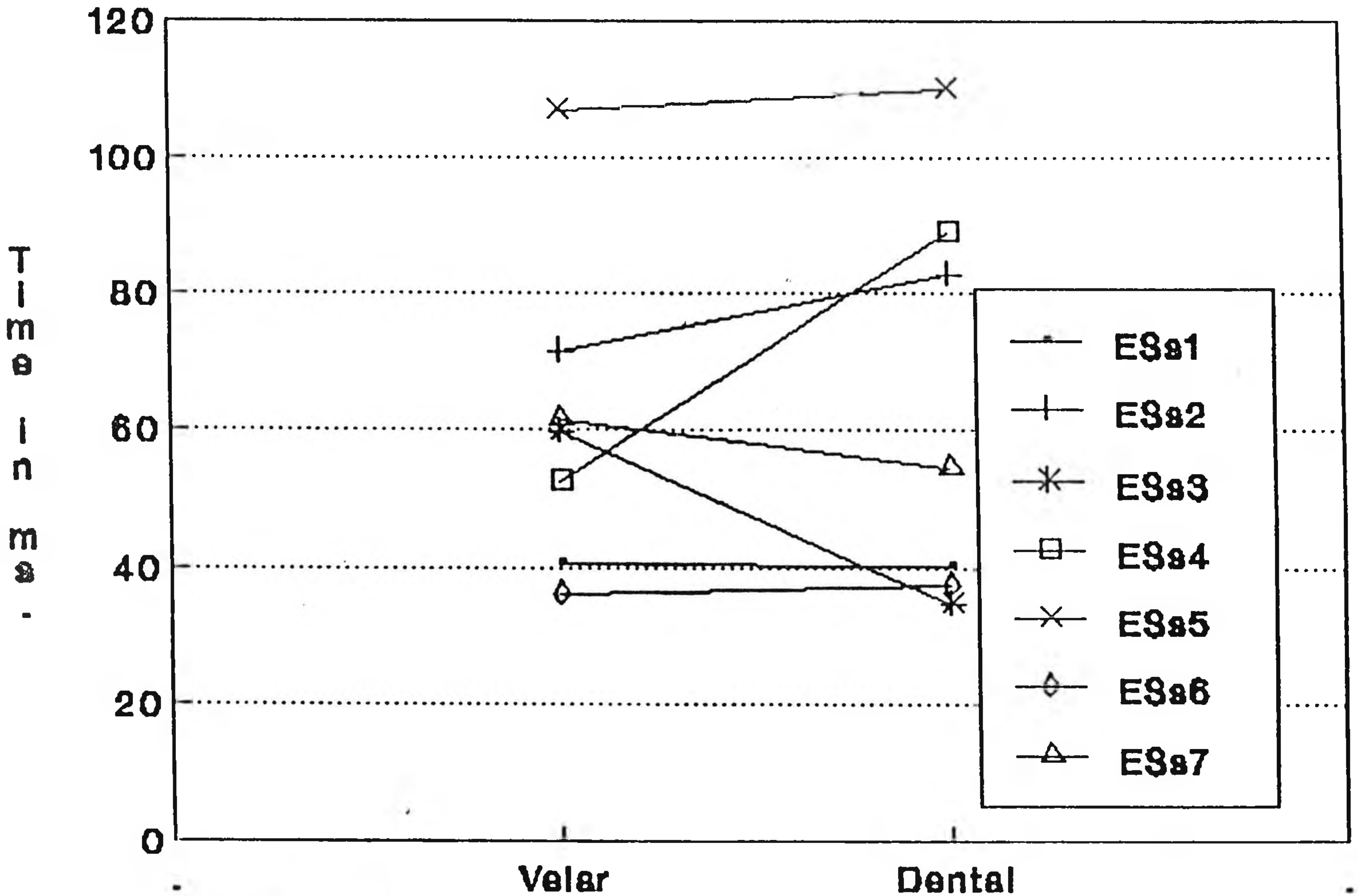

Fig.4.2.11b - The mean aspiration duration (Das) of initial velar and dental aspirated plosives spoken by each subject in Experimental group.

Table 4.2.16b:- The F-value and levels of significance for Duration of **Transient, and Aspiration segments** of minimal pairs attempted by subjects with velar fronting for various sources of variation.

Variable	sources of variation	df	F	P
Duration of Transient	Subject	6	6.7	.000
	Speech sound sound [k] & [t̲]	1	0.03	.86
	Subject X Speech sound [k] & [t̲]	6	.36	.9
Duration of Aspiration	Subject	4	30.4	.000
	Speech sound [k] & [t̲]	1	0.80	.38
	Subject X Speech sound [k] & [t̲]	4	4.21	.001

The duration of the transient and aspiration segments obtained from the output of the experimental group are compared to those obtained for control group I in Table 4.2.17. The mean Dtr values measured for the subjects who front velars appear to be larger than those obtained for control group I. The results of ANOVA for Dtr measure is available for the main effect of $[k^h]$~[$[\underline{t}^h]$ minimal pair, Type of subjects, and interaction effect (table 4.2.18). The obtained F-ratio indicates that the `velar fronters' have significantly larger transient durations ($p<.001$) than those with no production errors.

Tables 4.2.17:- The mean and SD of **duration of transient and aspiration segments** in the velar and dental initial minimal pairs attempted by control group I and Experimental group.

Segment of Analysis	/k^halI/		/$[\underline{t}^h$alI/	
	Control Group I Mean (SD)	Expt. Group Mean (SD)	Control Group I Mean (SD)	Expt. Group Mean (SD)
a) Transient	8.8 (8.8)	12.4 (5.0)	7.9 (2.6)	12.3 (4.6)
b) Aspiration	73.8 (25.6)	61.4 (28.8)	58.0 (27.5)	63.2 (34.6)

Table 4.2.18:- ANOVA table for the dependent variable **Dtr** and the main effects of $[k^h]\sim[[\underline{t}^h]$ minimal pair and type of subject group and interaction effect.

Sources of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects					
a) Type of Subjects	948.34	1	948.342	60.55	.000
b) $[k^h]\sim[[\underline{t}^h]$ minimal pair.	12.03	1	12.039	.76	.381
2-way Interactions (a X b)	9.54	1	9.541	.60	.436
Explained	970.69	3	323.564	20.66	.000
Error	3680.19	235	15.660		

The mean Das values measured for the subjects who front velars appear to be larger while targeting /k^halI/ and smaller while targeting /$\underline{t}^h$alI/ when compared to those obtained for control group I (Table 4.2.17). The completely randomised ANOVA was applied to the data in order to ascertain if the mean difference in Das measure was significant for the main effect of $[k^h]\sim[[\underline{t}^h]$ minimal pair and type of subject group and interaction effect (table 4.2.19). The obtained F-ratio was found not to be significant for the two main effects. However, here again interaction was significant beyond the .05 level. This indicates that the differences in aspiration duration for the two groups of subjects was different for the minimal pair attempted.

Table 4.2.19:- ANOVA table for the dependent variable **Das** and the main effects of [k^h]~[[$\underline{t}^h$] minimal pair and type of subject group and interaction effect.

Sources of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects					
a) Type of Subjects	714.00	1	714.000	.81	.369
b) [k^h]~[[$\underline{t}^h$] minimal pair.	1292.70	1	1292.704	1.47	.227
2-way Interactions (a X b)	4633.94	1	4633.943	5.26	.023
Error	207593.64	236	879.634		

ii) **Voice Onset Time:-**

The time between the moment of release and the start of periodicity was also measured (VOT).

1) **Control group I:-**

The mean and SD of VOT for the velars and dentals for each of the subjects is given in table 4.2.20a On applying ANOVA to the data significant differences existed for the main effects of Subjects ($F(4,90)=14.16$ $p<.001$) and the minimal a pair ($F(1,90)=31.84$ $p<.001$). This reflects that on VOT

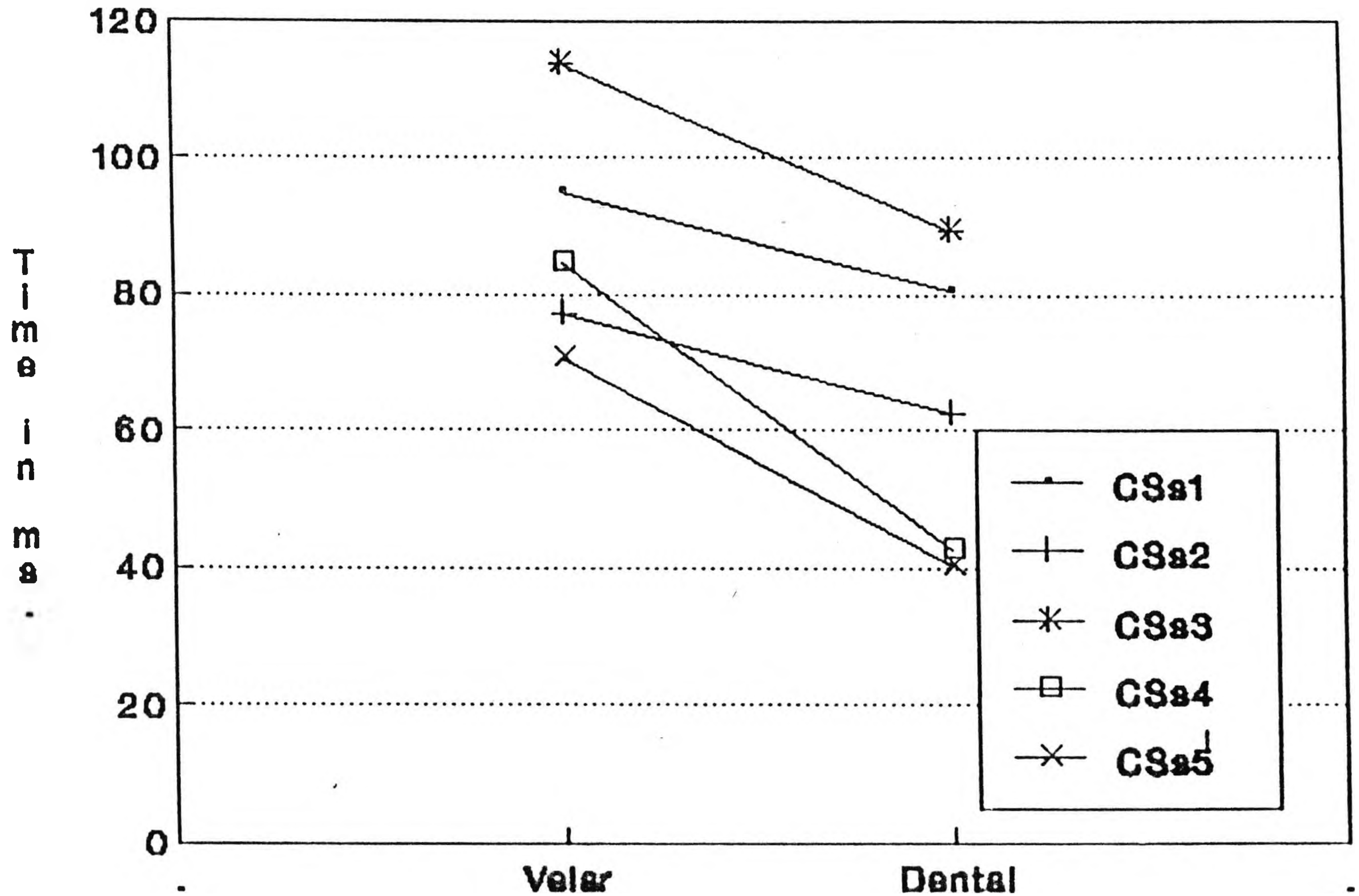

Fig. 4.2.12a:- The mean VOT of velar and dental aspirated initial plosive minimal pair spoken by each subject in Control group I.

measures the subjects were different and, furthermore, that there was an overall significant difference between VOT associated with velars and dentals. However, the lack of interaction (F(4,90)=1.37 p>.232) indicates that the difference in VOT for velars and dentals is similar for the different subjects. From Fig. 4.2.12a it is observed that the VOTs for velars are consistently larger than those for dentals.

Table 4.2.20a:- The mean and SD of **VOT** for the initial velars and dentals for each of the subjects with no production errors.

	/k^halI/		/$\underline{t}^h$alI/	
Ss	Mean (ms).	SD	Mean(ms).	SD.
CSs1.	95.1	11.2	80.7	20.0
CSs2.	77.1	17.0	62.4	36.5
CSs3.	113.8	21.2	89.6	29.1
CSs4.	84.7	23.7	42.5	16.0
CSs5.	70.8	20.2	40.3	17.9
Group	88.3	23.9	63.1	31.3

As predicted by findings in adult data (Lisker & Abramson, 1964; Fant, 1973; Kewley-Port, 1982) and in child data (Zlattin & Kenigsknecht, 1976; Eguchi & Hirsh, 1969; Macken & Barton, 1978; Young & Gilbert, 1988; Hewlett, 1988) for velars and alveolars, VOTs for velars are significantly greater than those for dentals in this study. The values are simillar to the VOT values obtained for adult speakers of initial stop consonant; however the difference was greater in the present data (Zlattin & Kenigsknecht, 1976; Lisker & Abramson, 1964). The findings hence contradict the observation of Hewlett (1988) that VOTs of children are larger than those of adults.

2) Experimental group:-

The mean and SD of VOT for the velars and dentals for each of the subjects with velar fronting is given in table 4.2.20b. On applying ANOVA to the data, significant difference was obtained for the main effect of Subject ($F(6,126)=31.5$, $p<.001$). However, the F-ratio for the difference between mean VOT for velar and dental aspirates attempted did not reach significance. A Significant interaction effect existed ($F(6,126)=4.2$ $p=.001$), which indicates that the difference in mean for the two sounds was different for these subjects. From the graph of mean VOT for the minimal pairs attempted by each velar fronting subject given in figure 4.2.12b, it is clear that subjects ESs2, ESs3, and ESs4 maintain relatively large mean VOT differences between the two members of the minimal pair. On application of Scheffee's test the obtained F-ratio indicates that the difference in means for the minimal pair was significant at the .01 level for subject ESs3 alone.

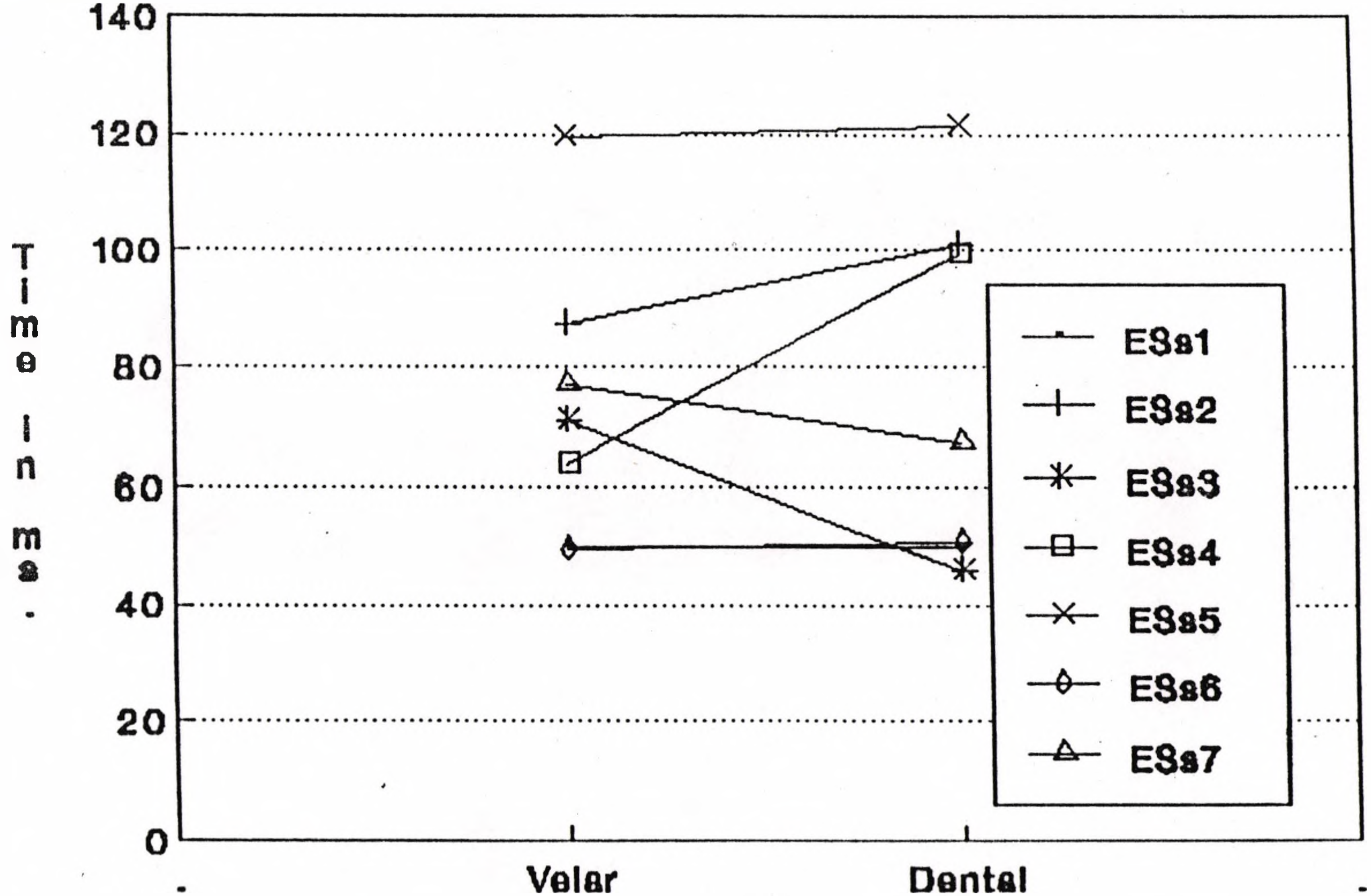

Fig.4.2.12b:- The mean VOT of velar and dental aspirated initial plosive minimal pair spoken by each subject in Experimental group.

Table 4.2.20b:- The mean and SD of **VOT** for the initial velars and dentals words attempted by subjects with velar fronting.

Ss	/k^hali/ Mean (ms)	SD	/$\underline{t}^h$ali/ Mean(ms)	SD.
ESs1.	49.8	7.7	49.8	10.7
ESs2.	87.1	23.8	100.9	21.3
ESs3.	70.8	19.1	45.8	21.9
ESs4.	63.6	22.9	99.4	18.4
ESs5.	119.3	9.4	121.4	33.3
ESs6.	49.4	23.0	50.8	15.7
ESs7.	76.9	22.3	67.3	29.0
Group	73.8	29.4	75.5	35.3

The obtained mean VOT values for the experimental group were compared to those obtained for control group I (Table 4.2.21). The mean VOT for control group I, appears to be larger than that for the experimental group when velars were targeted, while the reverse is true in the case of dentals. On application of completely randomised ANOVA, the obtained F-ratio indicates that there was significant difference for the main effect of [k^h]~[[$\underline{t}^h$] minimal pair and for the interaction (Table 4.2.22). This indicates that the VOTs tended to be different for the velar and dental initial words for the two groups. The obtained significant interaction effect indicates that the mean VOT difference between /k^hali/ and /$\underline{t}^h$ali/ was significantly different for the two groups of subjects. From table 4.2.21, it is apparent that mean VOT for /kʰali/ is greater than for /t̠ʰali/ for the control group I, while the reverse is true for subjects in the experimental group.

Tables 4.2.21:- The mean and SD of **voice onset time** in the velar and dental initial minimal pairs attempted by control group I and Experimental group.

Group	/kʰali/ Mean(ms)	SD	/t̠ʰali/ Mean(ms)	SD.
Control group I	88.3	23.9	63.1	31.3
Experimental group	73.8	32.2	76.5	35.3

Table 4.2.22:- ANOVA table for the dependent variable **VOT** and the main effects of [kʰ]~[[t̠ʰ] minimal pair and type of subject group and interaction effect.

Sources of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects					
a) Type of Subjects	16.74	1	16.741	.01	.894
b) [kʰ]~[[t̠ʰ] minimal pair	4815.10	1	4815.104	5.16	.024
2-way Interactions (a X b)	11305.36	1	11305.360	12.12	.001
Error	220087.75	236	932.575		

iii) **Duration of following vowel and the entire word.:-**

The time from onset of periodicity to the end of vowel steady state was taken as the duration of the vowel [a].

1)Control group I:-

The obtained mean and SD for various subjects is given in Table 4.2.23a. Significant differences were obtained for the main effect of subject ($F(4,90)=9.7$ $p<.001$) and the interaction of subject x sound ($F(4,90)=2.8$ $p<.05$). Thus the vowel durations were significantly different for different subjects and the difference in vowel [a] duration in the two minimal pairs were different for different subjects. However, the subjects did not make significant differences in this measure for the two test words. The lack of any consistent pattern in Fig.4.2.13a reflects this. The findings are similar to those of Fant(1973) who observed that vowel duration was approximately the same for all voiceless stops.

Table 4.2.23a:- The mean and SD of **vowel [a] duration** in the initial velars and dentals words for each of the subjects with no production errors.

	/k^halI/		/$\underline{t}^h$alI/	
Ss	Mean (ms).	SD	Mean(ms).	SD.
CSs1.	136.8	51.9	136.9	35.0
CSs2.	131.7	20.0	100.0	28.0
CSs3.	95.7	30.1	108.1	32.9
CSs4.	85.7	23.9	107.8	11.3
CSs5.	76.8	14.6	93.1	12.9
Group	105.3	38.5	109.1	29.3

The duration of the two words was measured from the onset of burst to the cessation of the second formant of the

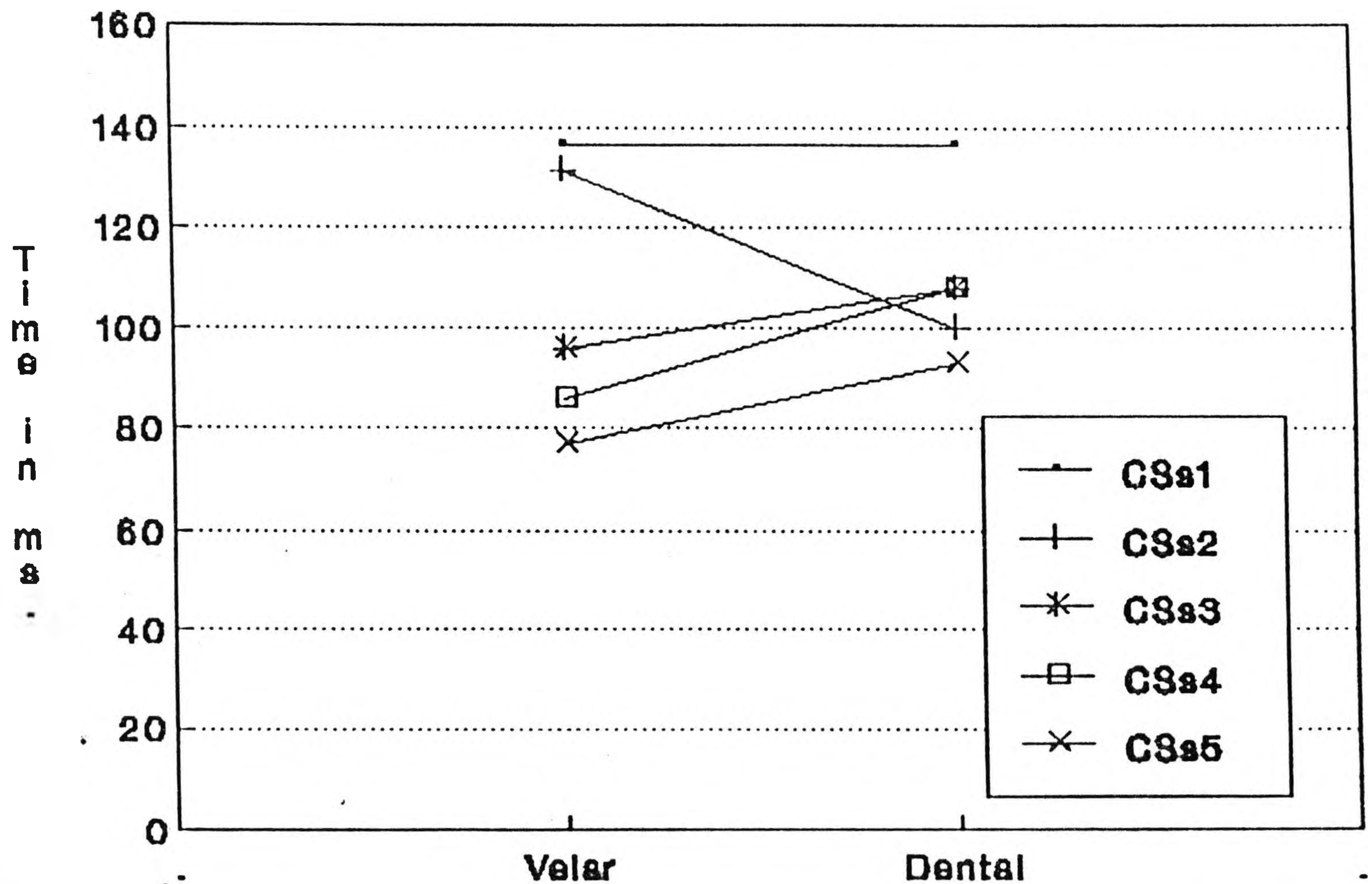

Fig. 4.2.130:- The mean duration of vowel [a] (D[a]) in initial velar and dental aspirated plosive minimal pair spoken by each subject in Control group I.

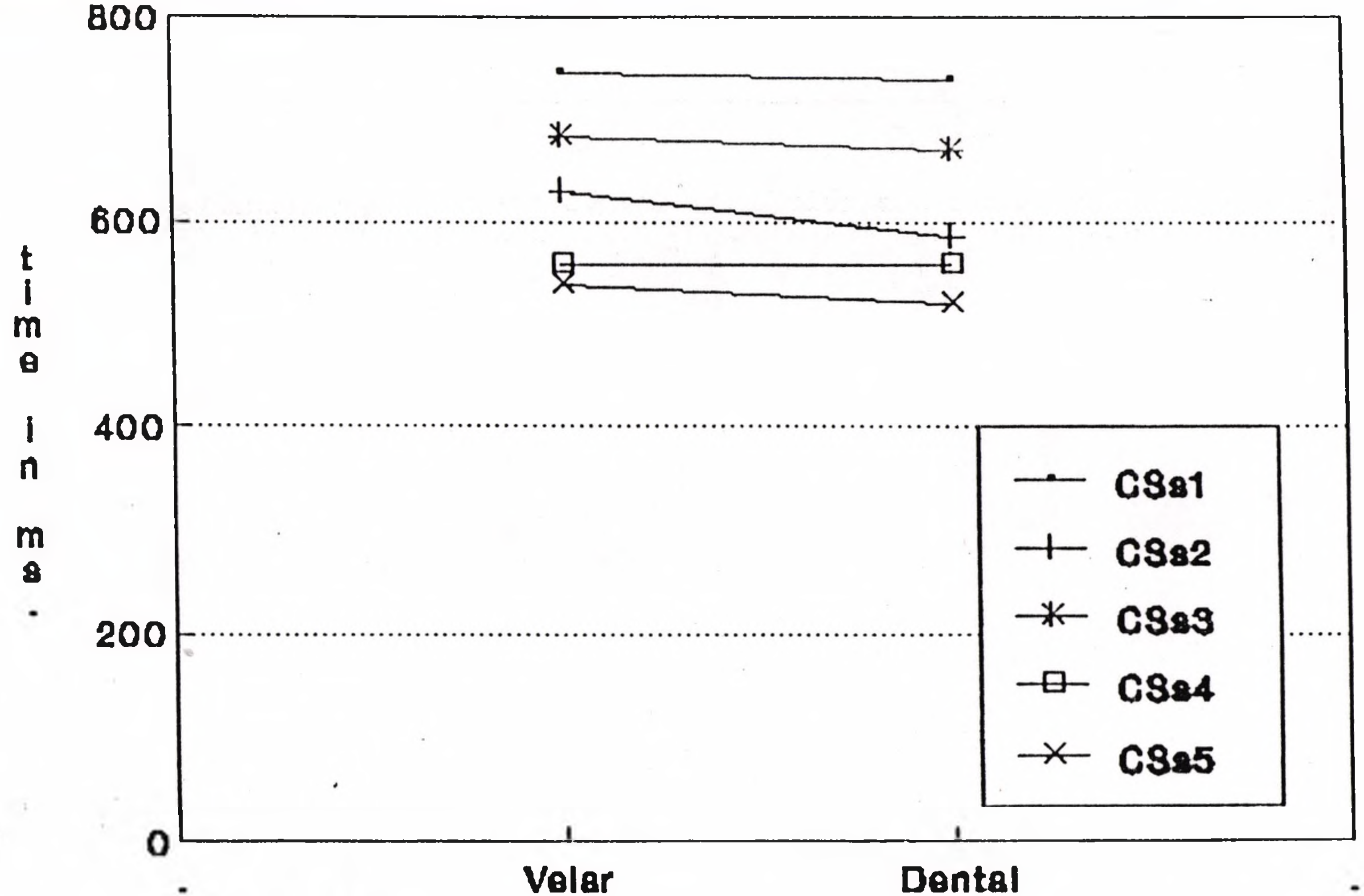

Fig. 4.2.14a- The mean duration of velar and dental aspirated initial plosive minimal pair words (Dwrd) spoken by each subject in Control group I.

final vowel and/or the voice bar. The mean and SD of word duration for the minimal pairs and each subject is given in table 4.2.24a. The obtained F ratio ($F(4,90)=22.7$ $p<.001$) indicates a significant difference in the time taken to say the word by each subject. However the subjects took the same time to say the target pairs. The nearly parallel lines in Fig.4.2.14a reflect the lack of difference.

Table 4.2.24a:- The mean and SD of **word duration (Dwrd)** for the two minimal pairs of interest for each of the subjects with no production errors.

	/k^halI/		/$\underline{t}^h$alI/	
Ss	Mean (ms)	SD	Mean(ms)	SD
CSs1.	745.6	62.9	729.4	117.7
CSs2.	630.1	63.3	587.0	131.8
CSs3.	684.5	88.3	670.9	117.7
CSs4.	559.6	30.4	557.9	43.2
CSs5.	537.3	39.3	519.4	47.7
Group	631.4	97.2	614.9	124.6

2) **Experimental group:-**

The obtained mean and SD of vowel [a] duration for various subjects with velar fronting is given in Table 4.2.23b. Significant differences were obtained for the main effects of subject ($F(6,126)=16.7$, $p<.001$) minimal pair ($F(6,126)=5.9$, $p<.02$). However, no significant interaction effects were obtained, indicating that the subjects maintained similar mean vowel duration differences between the

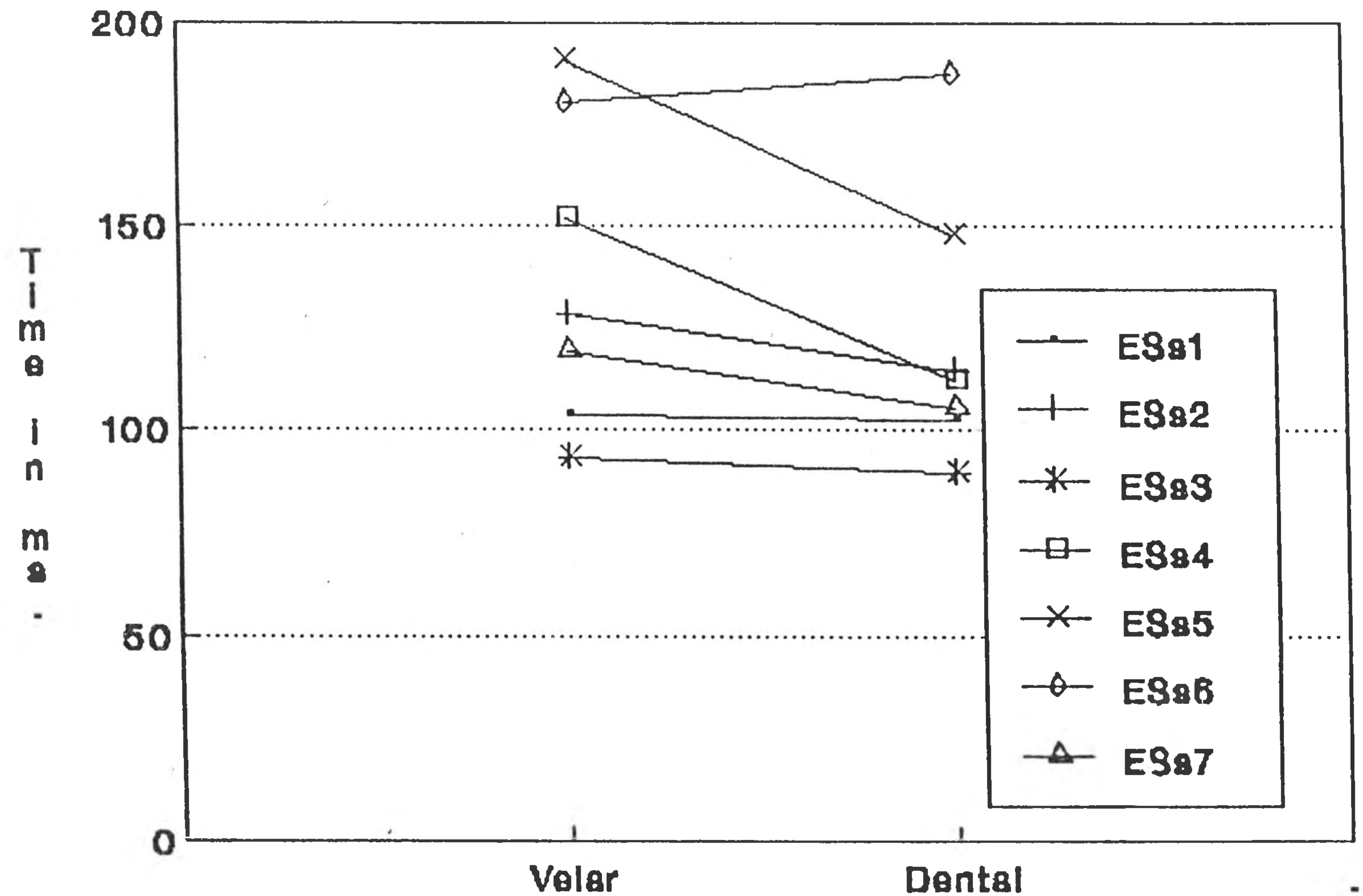

Fig. 4.2.13b The mean duration of vowel [a] (D[a]) in initial velar and dental aspirated plosive minimal pair spoken by each subject in Experimental group.

two attempted words. From figure 4.2.13b, it appears that subjects ESs5, ESs4, ESs7, ESs2, and ESs1 maintained progressively smaller differences.

Table 4.2.23b:- The mean and SD of **vowel [a] duration** in the initial velar and dental words attempted by subjects with velar fronting.

Ss	/k^hali/ Mean(ms).	SD .	/$\underline{t}^h$ali/ Mean(ms).	SD.
ESs1.	103.6	14.1	102.1	14.2
ESs2.	128.0	21.9	114.3	23.7
ESs3.	93.1	16.2	89.9	30.3
ESs4.	151.4	103.2	112.2	28.0
ESs5.	191.0	27.7	147.6	36.7
ESs6.	180.5	25.7	187.2	36.1
ESs7.	119.1	23.4	105.4	32.2
Group	138.1	54.7	122.7	42.2

The mean and SD of word duration for the minimal pairs for each subject is given separately in table 4.2.24b and Figure 4.2.14b. The obtained F-ratio ($F(6,126)=43.2$, $p<.001$) indicates a significant difference in the time taken to say the word by each subject in the experimental group. For the main effect of minimal pair, the F-ratio indicates that there was significant difference in the time taken by the subjects to say /k^halI/ and /$\underline{t}^h$alI/ ($F(1,126)=4.1$, $p<.05$). The interaction effects were not significant.

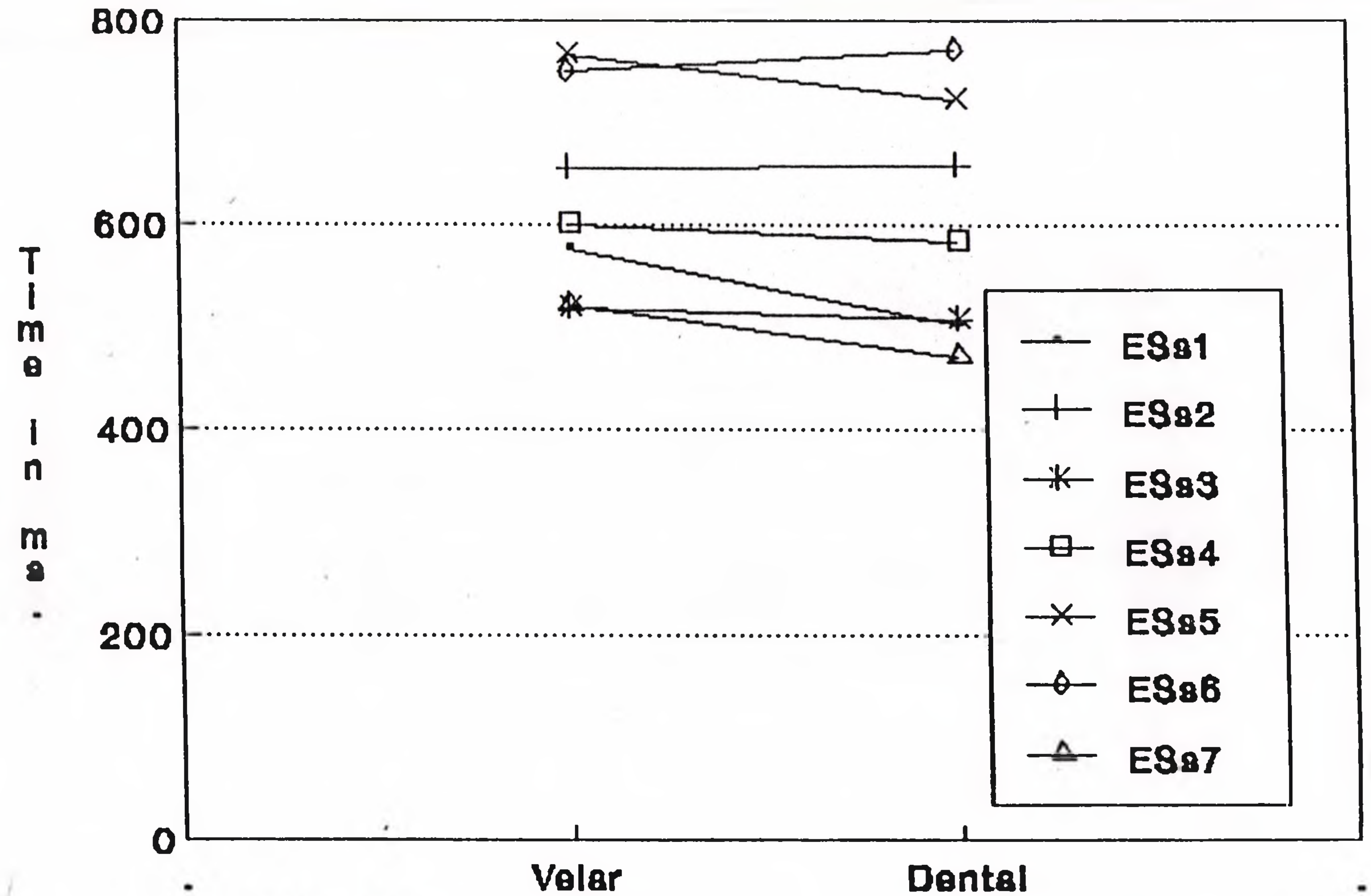

Fig 4.2.14b:- The mean duration of velar and dental aspirated initial plosive minimal pair words (Dwrd) spoken by each subject in Experimental group.

Table 4.2.24b:- The mean and SD of **word duration (Dwrd)** for the minimal pairs of interest attempted by subjects with velar fronting.

Ss	$/k^{h}ali/$ Mean (ms.)	SD	$/\underline{t}^{h}ali/$ Mean(ms.)	SD.
ESs1.	577.4	116.6	502.7	56.3
ESs2.	654.3	79.6	656.2	79.7
ESs3.	519.3	43.1	508.0	98.8
ESs4.	600.1	46.1	582.9	29.7
ESs5.	764.7	47.7	721.3	25.1
ESs6.	749.3	80.5	770.6	110.0
ESs7.	522.8	33.4	471.6	91.1
Group	626.8	114.7	601.9	131.2

The mean vowel [a] durations for the control and experimental groups were compared in table 4.2.25(a). On application of ANOVA, the obtained F-ratio for the main effect of subject type was found to be significant beyond the .001 level ($F(236)=164$, $p<.001$), indicating that the experimental group was maintaining larger vowel duration than the, control group. The mean word duration for control group I and the experimental group are compared in table 4.2.25(b). There appears to be very little difference between the two groups for this acoustic variable. On application of ANOVA, the obtained F-ratio indicated that there was no significant difference between the mean word duration obtained for the control group I and the experimental group.

Tables 4.2.25:- The mean and SD of **duration of vowel [a] and that of the vowel [a]** in the velar and dental initial minimal pairs attempted by control group I and Experimental group.

Segment of Analysis	$/k^{h}alI/$		$/[\underline{t}^{h}/$	
	Control Group I Mean (SD)	Expt. Group Mean (SD)	Control Group I Mean (SD)	Expt. Group Mean (SD)
(a) Vowel [a]	105.3 (38.5)	139.2 (55.7)	109.1 (29.3)	122.7 (43.4)
(b) Word	631.4 (97.2)	626.8 (114.7)	614.9 (124.9)	602.2 (131.2)

D) Fundamental Frequency:-

This was measured at the beginning of vowel [a] steady state.

1) Control group I:-

The mean and SD are provided in table 4.2.24a. On application of ANOVA a significant difference ($F(4,90)=72.3$ $p<.001$) was obtained only for the main effect of subject. From Fig.4.2.15a it is clear that subjects could be grouped into categories with CSs2, CSs3, and CSs5 having lower Fo than CSs1 and CSs4. This could not be correlated to the sex of the subjects.

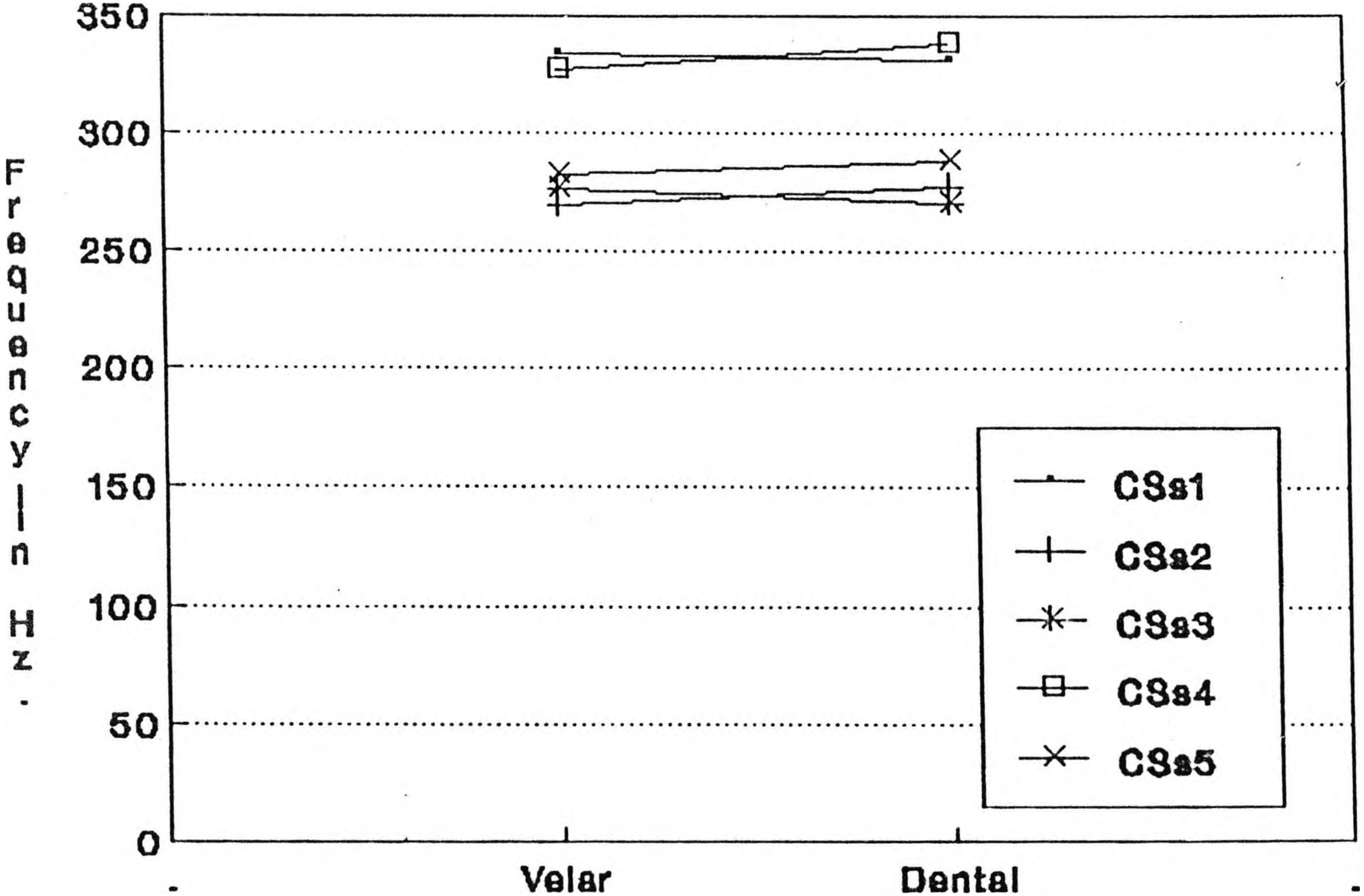

Fig. 4.2.15a:- The mean fundamental frequency of measured in the steady state segment of vowel [a] in the minimal pair spoken by each subject in Control group I.

Table 4.2.26a:- The mean and SD of **Fundamental frequency** used while speaking the minimal pairs of interest for each of the subjects with no production errors.

Ss	/k^halI/ Mean (Hz)	SD	/$\underline{t}^h$alI/ Mean (Hz).	SD.
CSs1.	334.2	9.1	331.4	11.1
CSs2.	269.5	11.5	277.0	19.6
CSs3.	276.2	12.3	270.5	5.6
CSs4.	327.0	23.9	338.0	27.9
CSs5.	282.6	12.9	288.5	12.7
Group	297.9	31.8	301.1	32.9

2)**Experimental group:-**

The means of F0 and of SD calculated for this group are provided in table 4.2.26b. On application of ANOVA significant differences ($F(6,126)=49.6$, $p<.001$) were obtained only for the main effect of subject. From Fig.4.2.15b, it may be observed that subject ESs4 has a considerably higher F0 than rest of the group (mean=468Hz). The other subjects tended to cluster around 350 Hz. Compared to children with no production errors, \`velar fronters' had considerably higher mean Fo (Table 4.2.26b). The obtained F-ratio indicated that the experimental group had significantly higher F0 than control group I ($F(1, 236)=152.2$, $p<.001$).

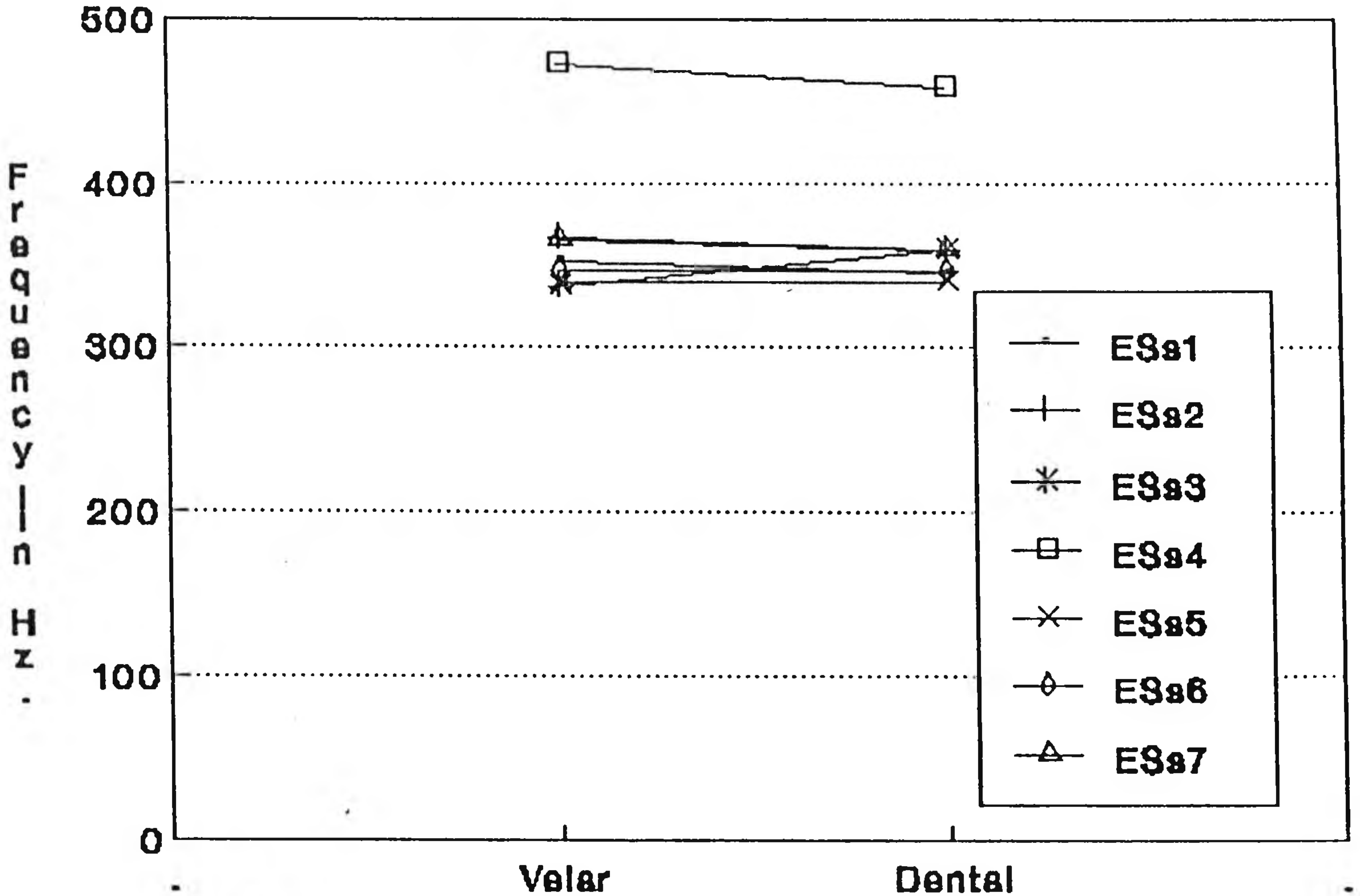

Fig.4.2.15b:- The mean fundamental frequency of measured in the steady state segment of vowel [a] in the minimal pair spoken by each subject in Experimental group.

Table 4.2.26b:- The mean and SD of **Fundamental frequency** used while speaking the minimal pairs of interest for each of the subjects with velar fronting.

Ss	/k^hali/ Mean(Hz).	SD	/$\underline{t}^h$ali/ Mean(Hz).	SD.
ESs1.	353.8	13.8	346.0	28.7
ESs2.	367.4	21.8	360.1	15.7
ESs3.	337.9	12.3	361.0	42.5
ESs4.	473.4	39.4	458.8	58.7
ESs5.	340.2	13.1	340.1	10.0
ESs6.	347.5	27.4	348.2	17.3
ESs7.	366.4	22.2	359.8	18.8
Group	369.5	49.3	367.7	49.4

Tables 4.2.27:- The mean and SD of **fundamental frequency** used while speaking minimal pair by control group I and Experimental group.

Type of subject	/k^hali/ Mean(ms).	SD	/$\underline{t}^h$ali/ Mean(ms).	SD.
Control group I	297.9	31.8	301.1	32.9
Experimental group	369.5	49.3	368.2	49.4

E) **Movement of F2 related peak:-**

It has been speculated that the dynamic change of the formant pattern as a function of time reflects place of articulation (Liberman, et al 1967; Kewley-port, 1983; Fant, 1973). Usually transitions are computed in the periodic portion of CV. Fant (1973) measured the F2 frequency at the instant of release and at the instant of periodicity in initial aspirated plosives as the transition in the vowel segment may be minimal. The transition for apical plosives has been reported as much more rapid than that for back of tongue plosives (Fant,`73). Given the difficulty in tracking formants in voices with high fundamental frequency or in aperiodic regions of aspiration, no direct attempt was made to do so. However, it was speculated that the rate of transition would be reflected in the difference between F2tr and F2fr and F2tr and F2[a]. It may be reasoned that larger differences would reflect quicker transitions and vise versa.

1) Control group I:-

Table 4.2.28a and 4.2.29a shows mean and SD of F2tr-F2fr and F2tr-F2[a] for /k^{h}ali/ and /$\underline{t}^h$ali/ attempted by each subject. The graph in figure 4.2.16a and 4.2.17a gives the mean F2tr-F2fr and F2tr-F2[a] values respectively. Although the variance was very large in all subjects except CSs2, the dental had larger differences compared with velars. The values in parenthesis in Table 4.2.28a and 4.2.29a, indicate the number of negative values in the data for each subject. Although the data is limited, CSs1 and CSs4 show the presence of negative values for F2tr-F2fr, significantly more in velars (34%) than in dentals (18%). Generally F2 transitions have been represented as straight descending lines for velars and apical sounds. A negative F2tr-F2fr value indicates that the F2 related peak

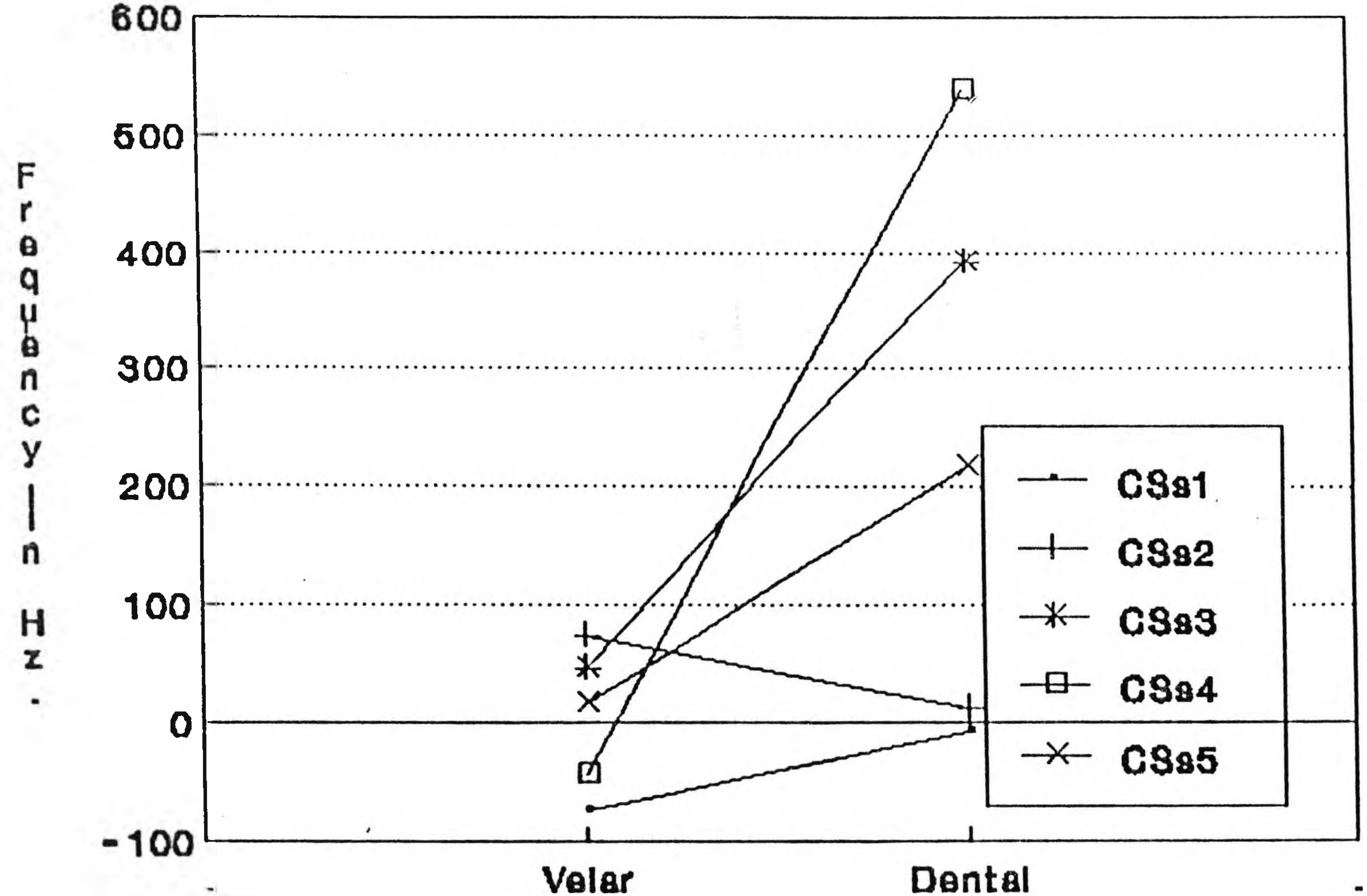

Fig. 4.2.16a:- The mean F2tr-F2fr for velar and dental aspirated initial plosive minimal pair spoken by each subject in Control group I.

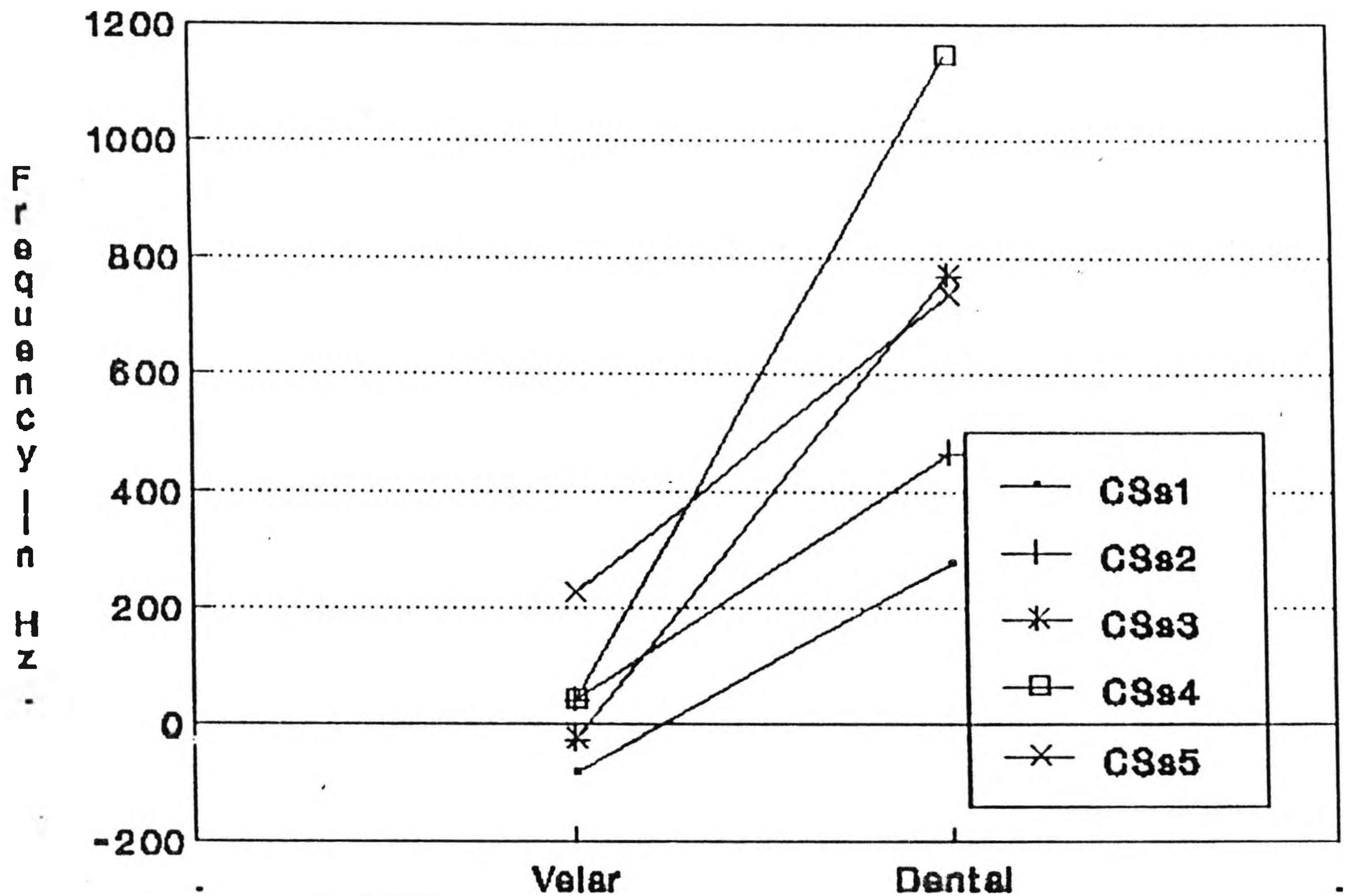

Fig. 4.2.17a:- The mean F2tr-F2[a] for velar and dental aspirated initial plosive minimal pair spoken by each in subject Control group I.

actually ascends from the point of release to a post-transient segment before descending to connect with F2 of the aspiration and vowel [a]. While a negative F2tr-F2[a] value indicates that the F2 transitions are ascending and not descending. Table 4.2.29a demonstrates that this was true for about 44% of velars. Furthermore, this was true for all subjects except Subject CSs5, who had only one such instance. The F2tr-F2fr and F2tr-F2[a] values provide a rough approximation of the transition. So the movement of F2 related peak was plotted for the two sound types for each subject separately in Fig.4.2.18, 4.2.19, 4.2.20, 4.2.21, and 4.2.22.

Table 4.2.28a :- The mean and SD of **F2tr-F2fr** for the minimal pairs for each of the subjects with no production errors. The values in parenthesis indicate the number of negative values.

	/k^halI/		/$\underline{t}^h$alI/	
Ss	Mean (Hz)	SD	Mean (Hz).	SD.
CSs1.	-74.3 (6)	148.2	-8.3 (4)	73.5
CSs2.	75.0 (1)	67.5	11.3 (1)	249.0
CSs3.	47.0 (1)	110.4	391.8	372.8
CSs4.	-44.5 (6)	246.1	538.9 (3)	789.2
CSs5.	15.3 (3)	185.8	215.6 (1)	276.5
Group	3.7 (17)	166.5	249.7 (9)	453.0

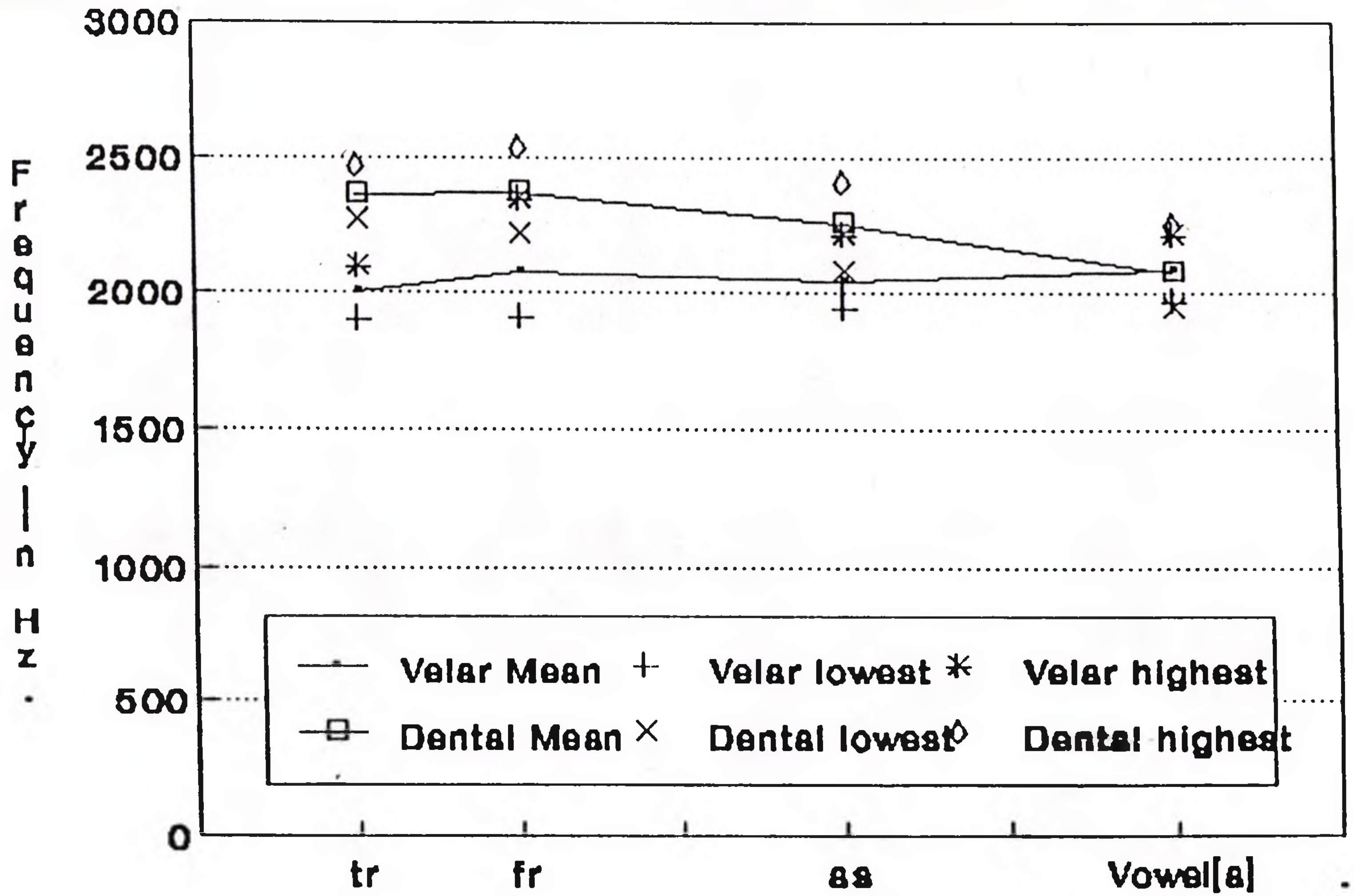

Fig. 4.2.18:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by CSs1 in Control group I (Transient (tr), Post-transient (fr), and Aspiration (as)).

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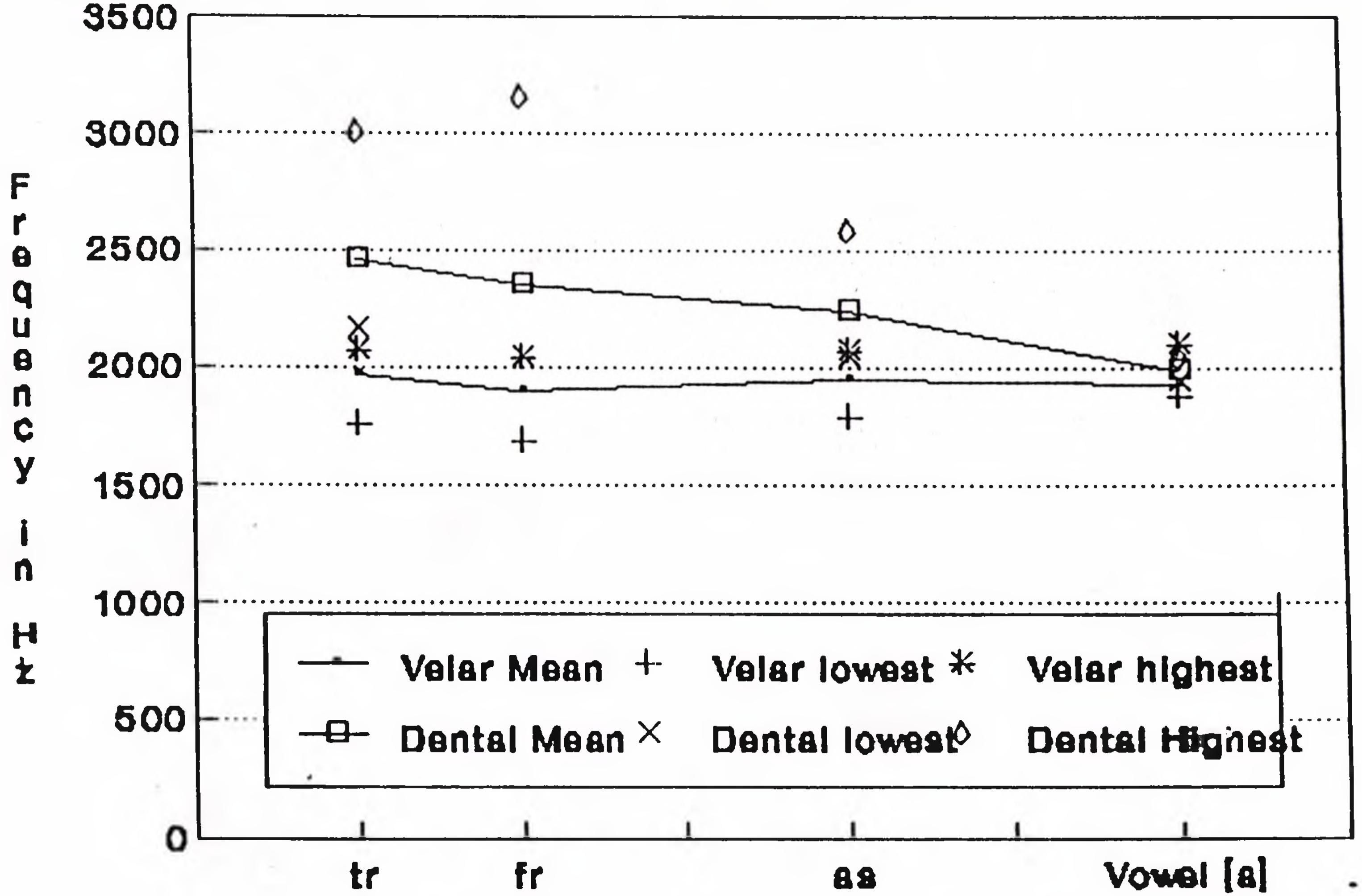

Fig. 4.2.19:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by CSs2 in Control group I (Transient (tr), Post-transient (fr), and Aspiration (as))

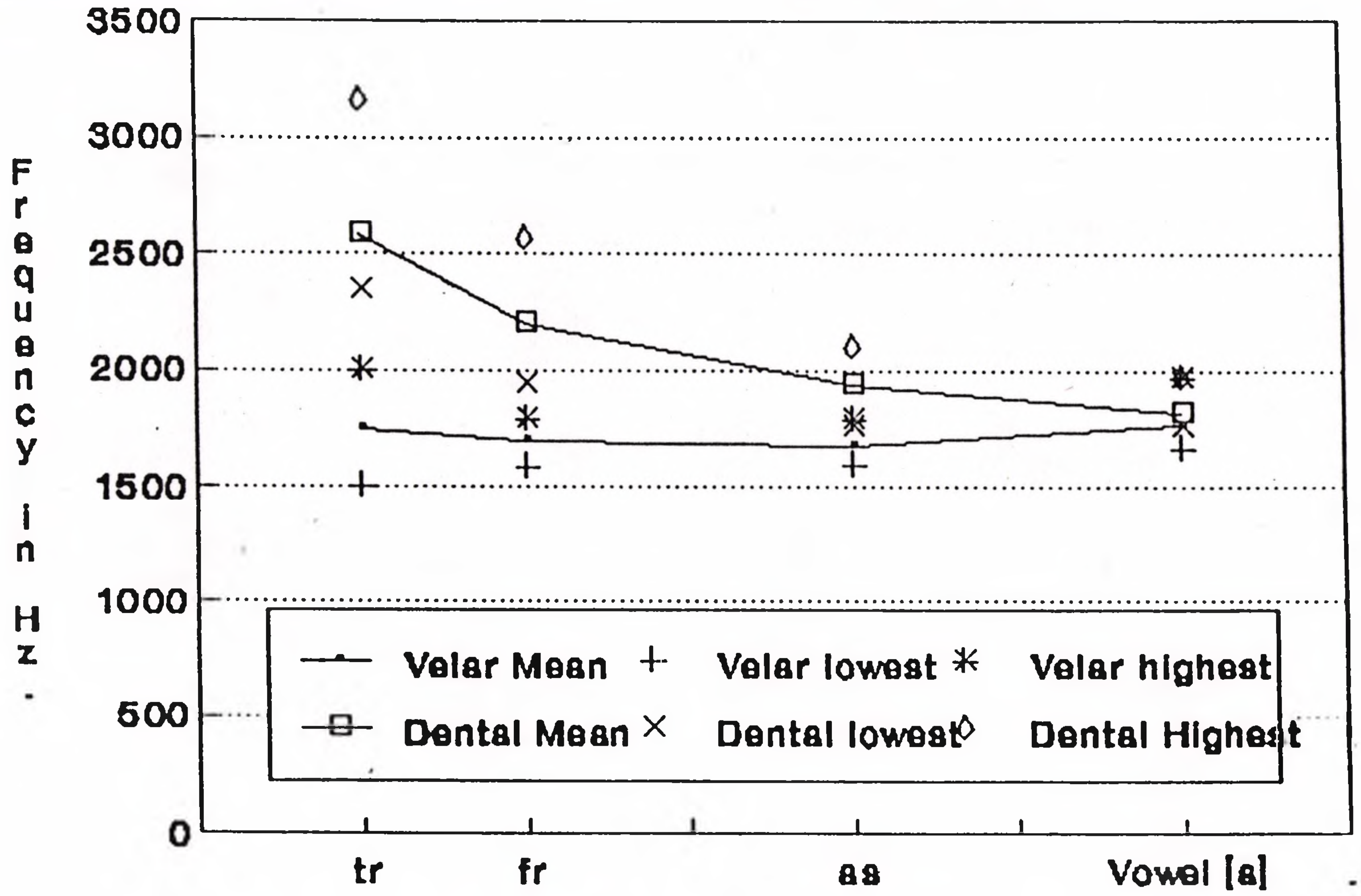

Fig. 4.2.20:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by CSs3 in Control group I (Transient (tr), Post-transient (fr), and Aspiration (as)).

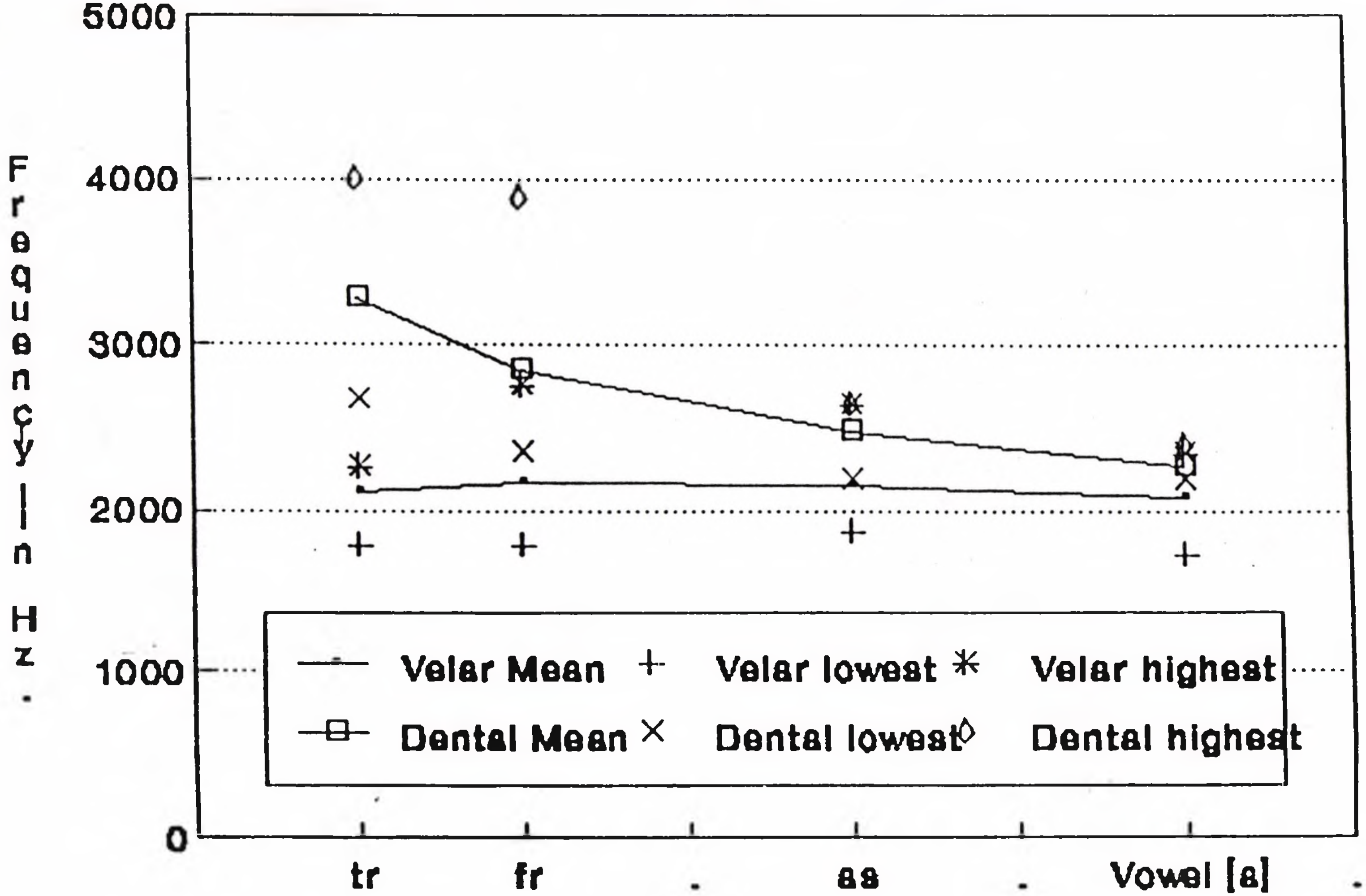

Fig. 4.2.21:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by CSs4 in Control group I(Transient (tr), Post-transient (fr), and Aspiration (as)).

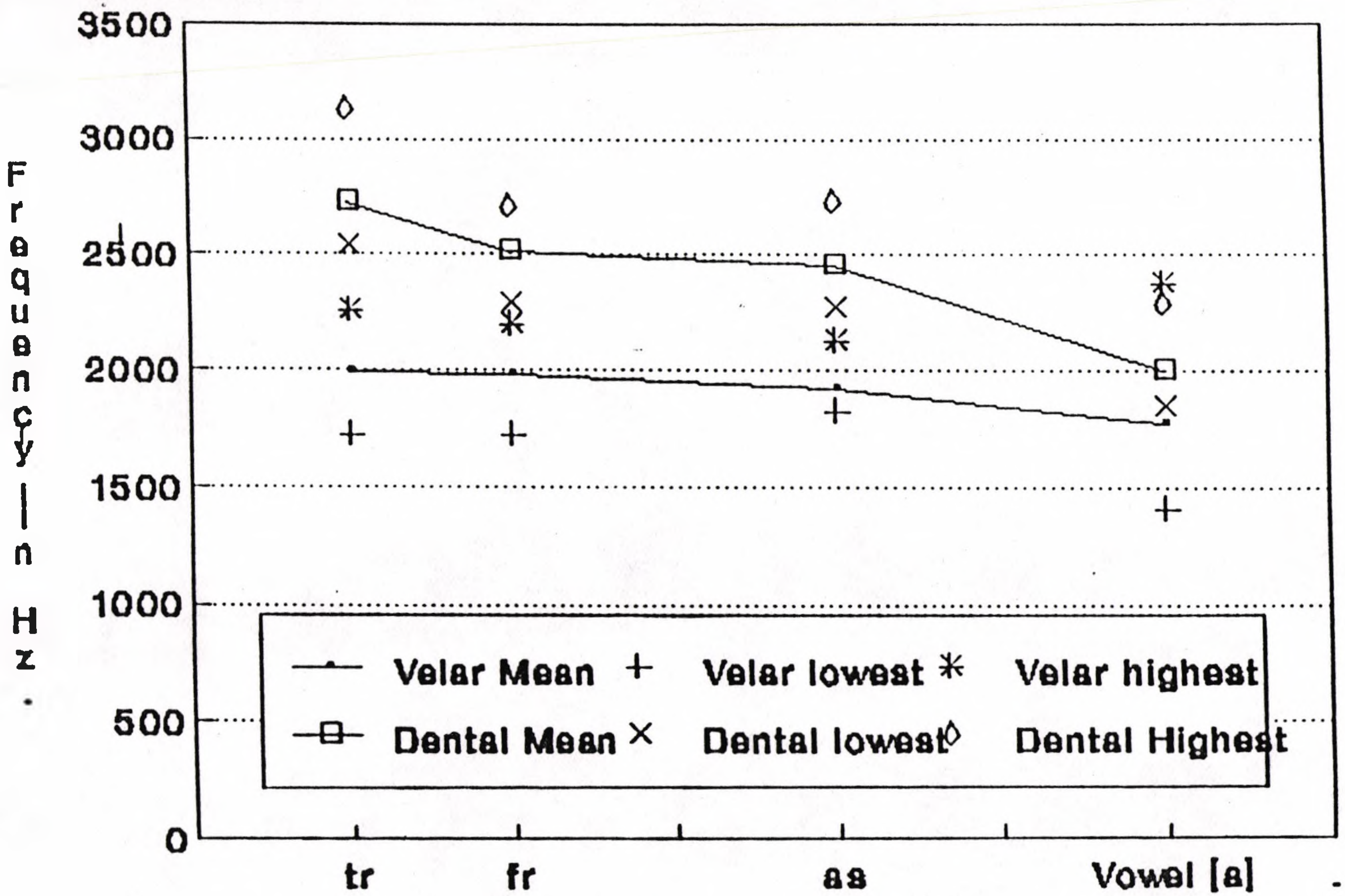

Fig. 4.2.22:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by CSs5 in Control group I (Transient (tr), Post-transient (fr), and Aspiration (as)).

Table 4.2.29a :- The mean and SD of **F2tr-F2 [a]** for the minimal pairs for each of the subjects with no production errors. The values in parenthesis indicate the number of negative values.

	/k^halI/		/$\underline{t}^h$alI/	
Ss	. Mean (Hz)	.SD	. Mean (Hz).	SD.
CSs1	-84.7 (7)	112.4	277.7	72.0
CSs2	40.8 (4)	111.6	466.7	260.0
CSs3	-26.4 (6)	80.4	769.4	328.6
CSs4	39.9 (4)	248.0	1146.7	759.4
CSs5	226.7 (1)	275.6	731.5	234.3
Group	39.3 (22)	216.9	678.	488.0

2) **Experimental group:-**

Table 4.2.28b and 4.2.29b shows mean and SD of F2tr-F2fr and F2tr-F2[a] /k^halI/ and /$\underline{t}^h$alI/ attempted by each of the subjects in the experimental group. Graphs of the means of these two values are available in figure 4.2.16b and 4.2.17b. The T-test for dependent sample indicated that there was no significant difference in group means for this parameter. F2tr-F2fr and F2tr-F2[a] values obtained for the experimental group are compared to the values obtained for control group I in Table 4.2.30. The t-test for independent sample was applied to ascertain if the mean values obtained for the two groups of subjects significantly differed for /k^hali/ and /$\underline{t}^h$ali/. The obtained t-value was not significant at the .05 level. Furthermore, the mean, lowest and highest F2 related peak for different segments was plotted

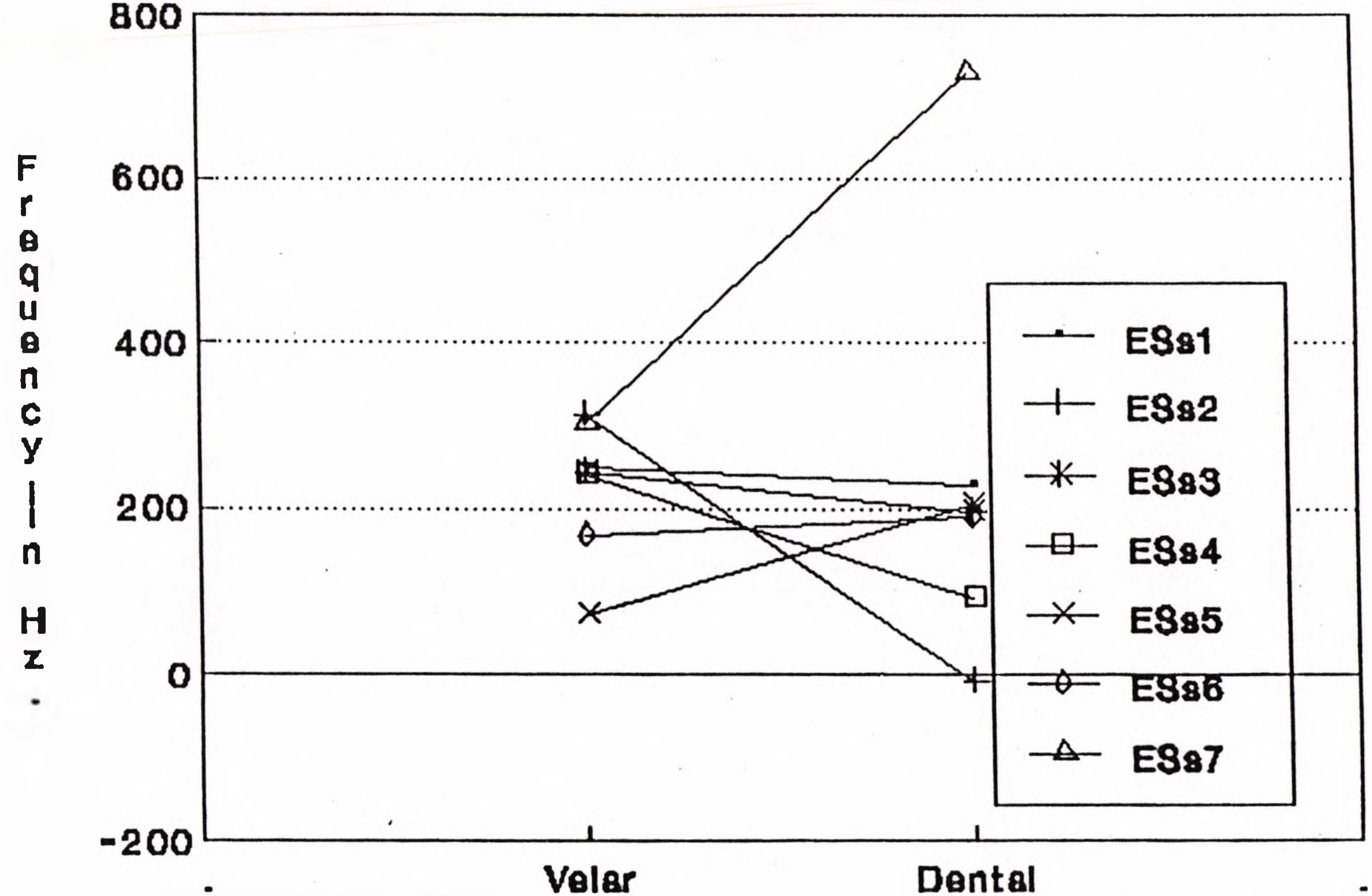

Fig.4.2.16b; The mean F2tr-F2fr for velar and dental aspirated initial plosive minimal pair spoken by each subject in Experimental group.

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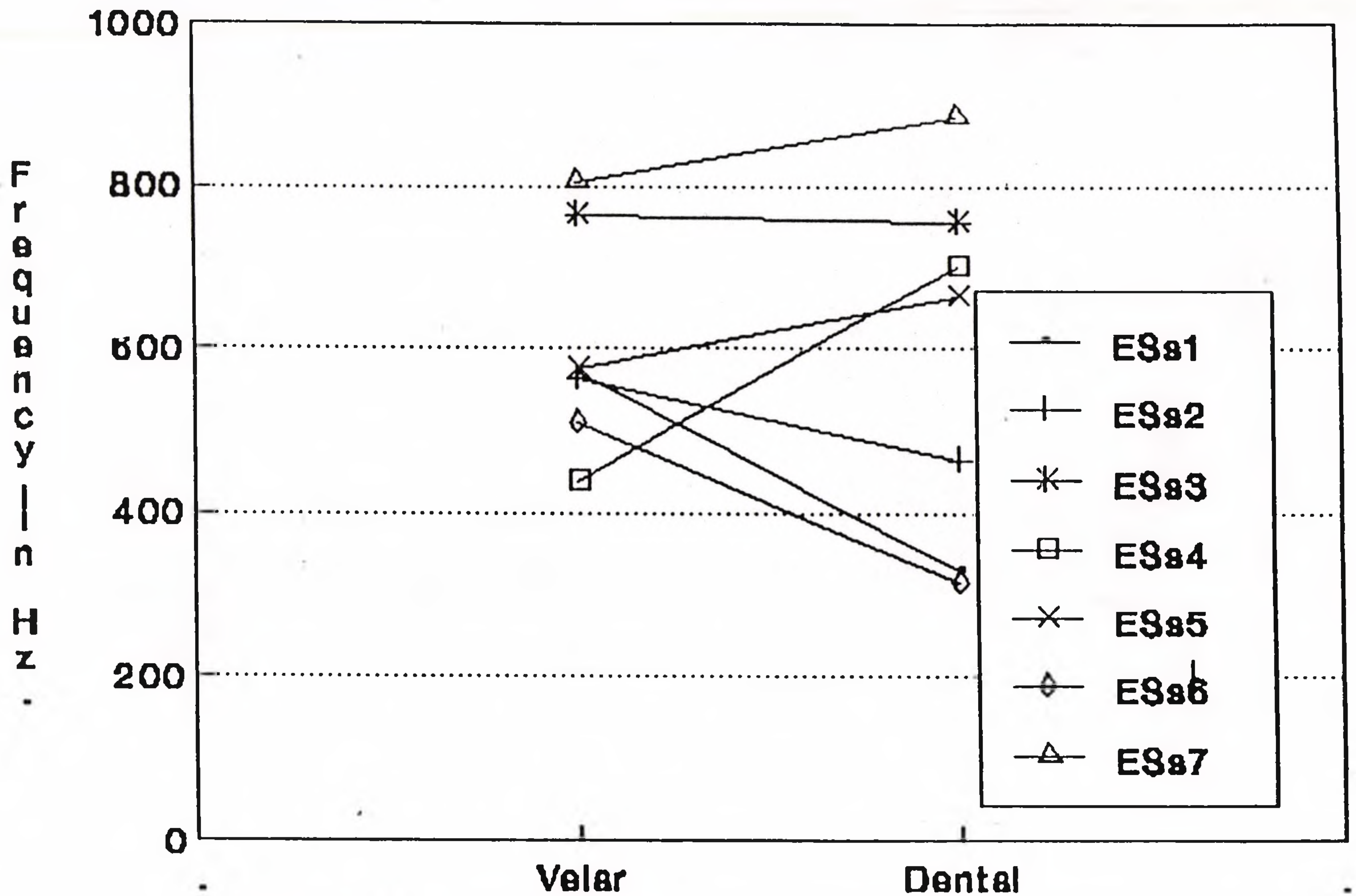

Fig.4.2.17b- The mean F2tr-F2[ɐ] for velar and dental aspirated initial plosive minimal pair spoken by each subject in Experimental group.

for the two sound types for each subject separately in Fig. 4.2.23, 4.2.24, 4.2.25, 4.2.26, 4.2.27, 4.2.28, and 4.2.29.

Table 4.2.28b:-The mean and SD of **F2tr-F2fr** for the minimal pairs of interest for each of the subjects with velar fronting. The values in parenthesis indicate the number of negative values.

	/kʰali/		/t̠ʰali/	
Ss	Mean (Hz)	SD	Mean (Hz)	SD
ESs1	247.6(1)	212.0	228.2(4)	611.4
ESs2	312.5(2)	628.6	-6.3(5)	240.2
ESs3	243.5(2)	331.5	253.6(3)	554.1
ESs4	240.9(2)	356.4	92.2(3)	359.2
ESs5	73.2(3)	348.8	203.8(2)	255.3
ESs6	168.8(1)	205.2	191.2	235.7
ESs7	298.9(3)	515.2	728.9(1)	543.4
Group	226.5(14)	387.5	233.5(18)	463.3

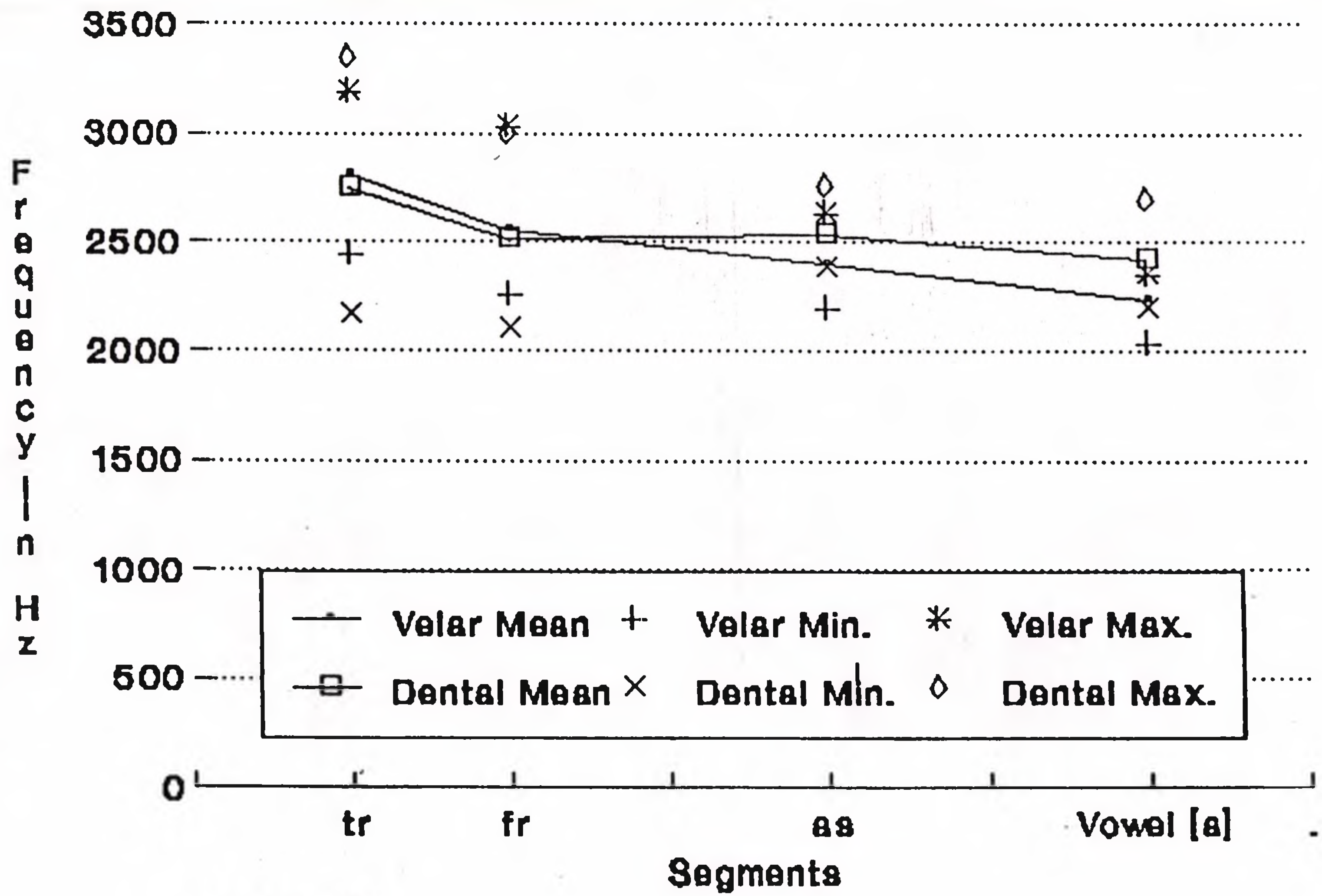

Fig.4.2.23.:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by ESs1 in Experimental group (Transient (tr), Post-transient (fr), and Aspiration (as)).

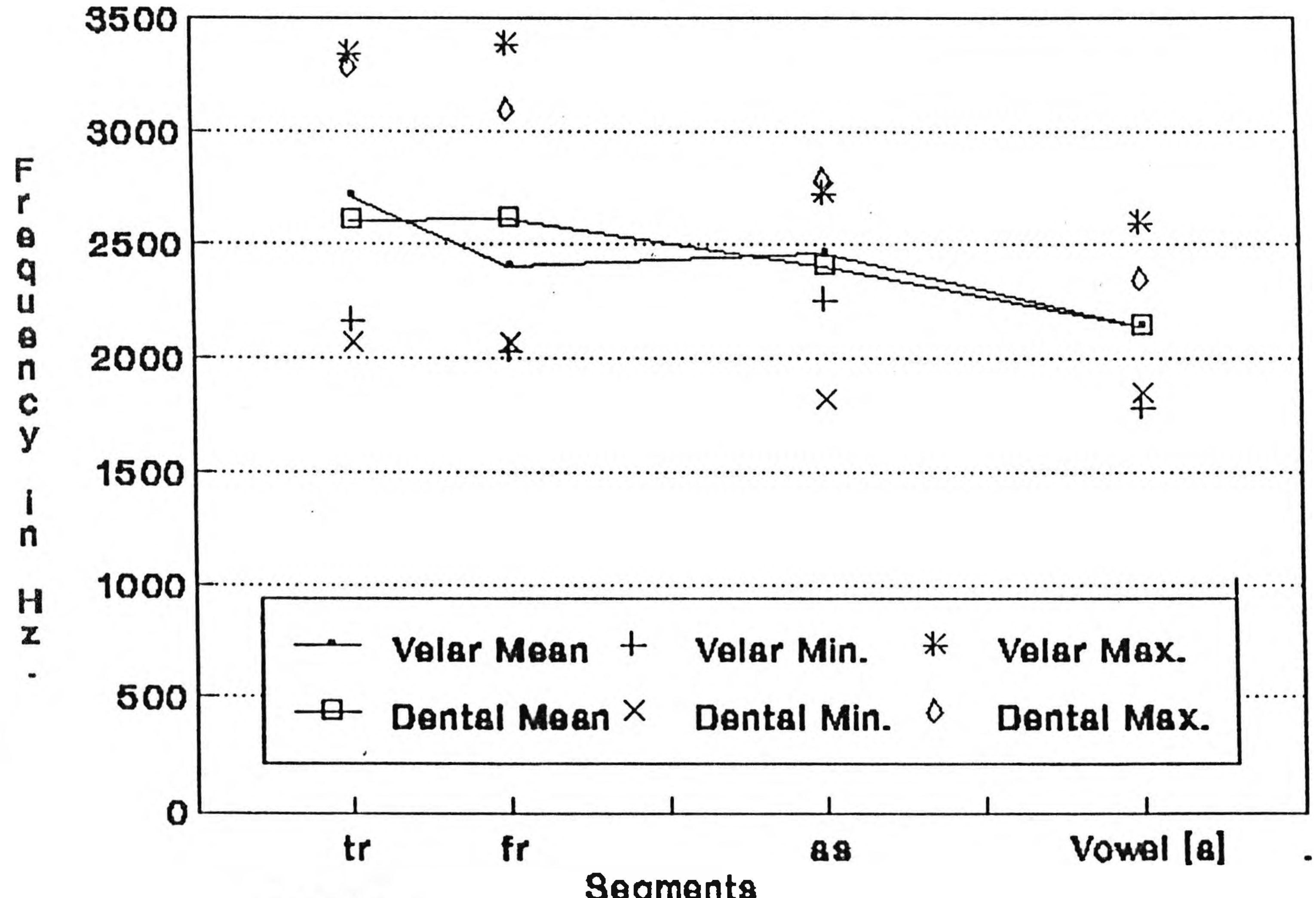

Fig.4.2.24:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by ESs2 in Experimental group (Transient (tr), Post-transient (fr), and Aspiration (as)).

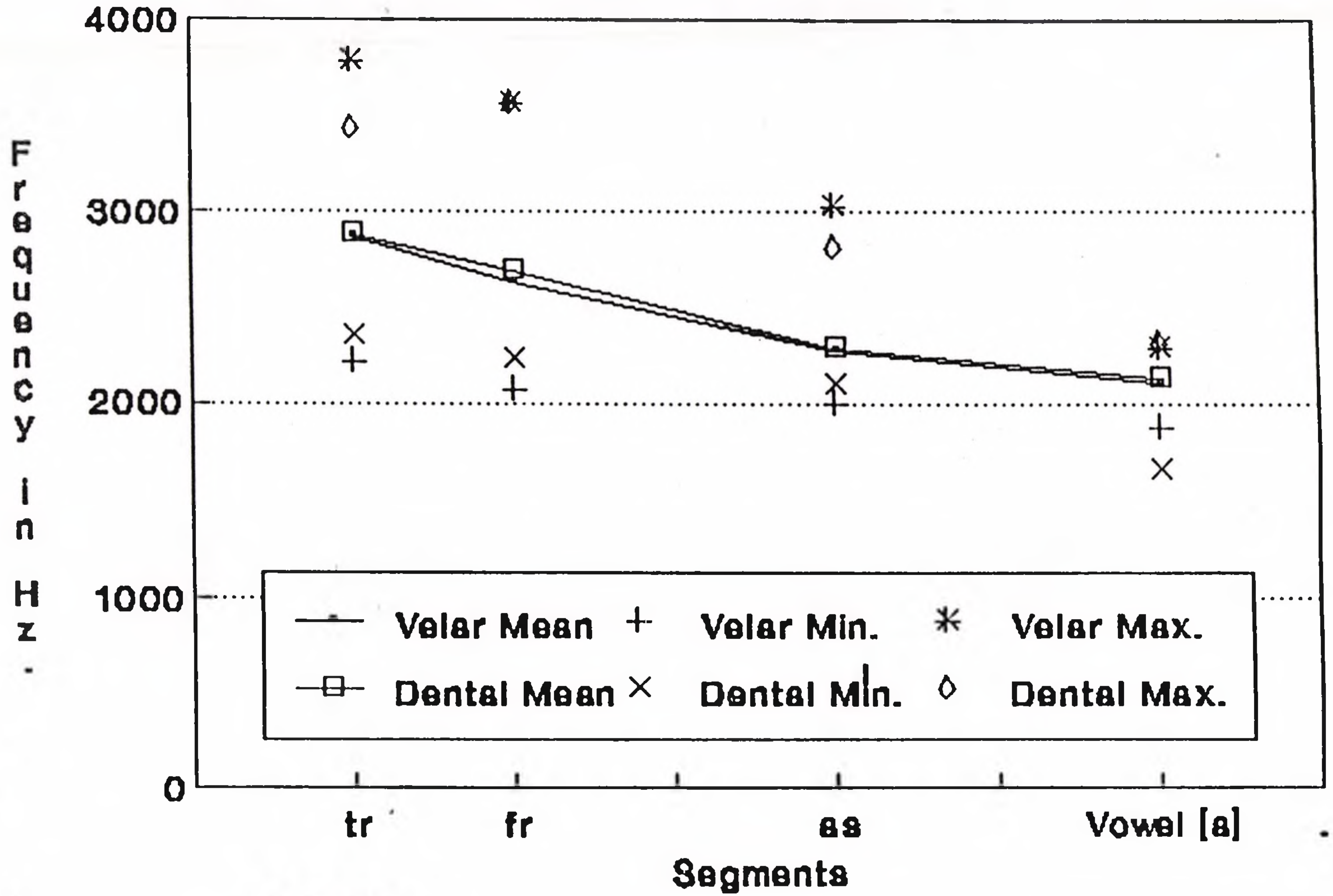

Fig.4.2.25:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by ESs3 in Experimental group (Transient (tr), Post-transient (fr), and Aspiration (as)).

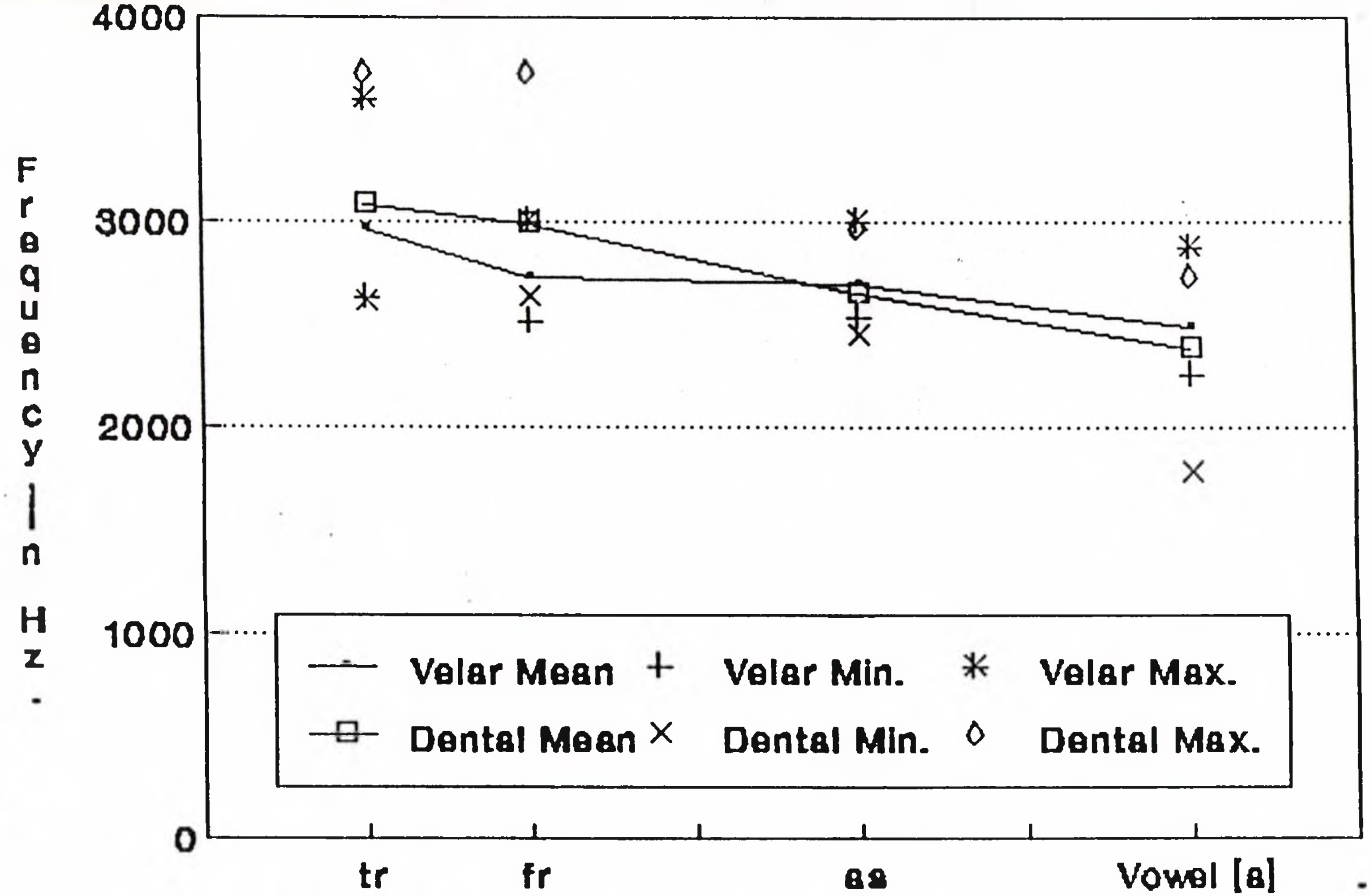

Fig.4.2.26:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by ESs4 in Experimental group (Transient (tr), Post-transient (fr), and Aspiration (as)).

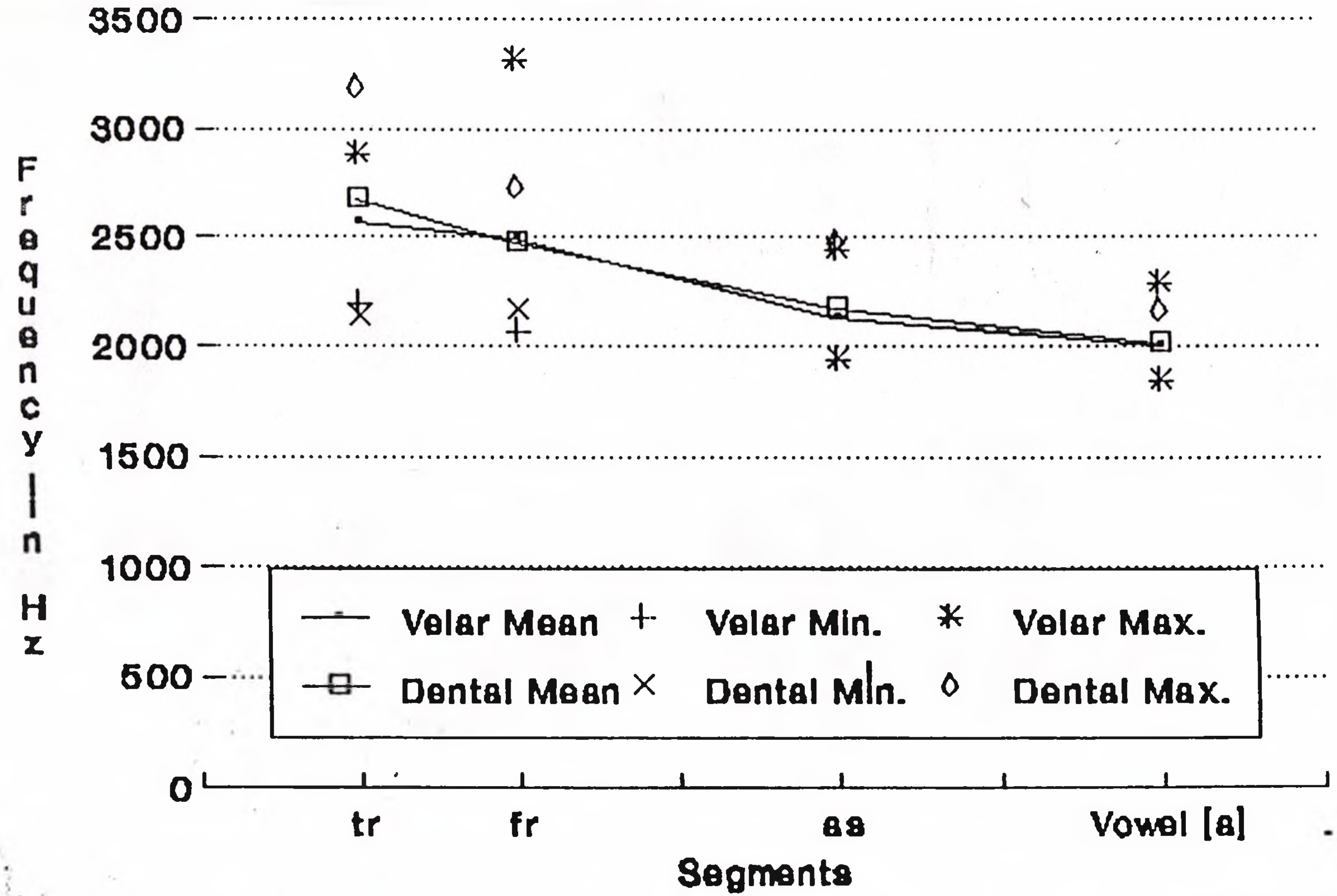

Fig.4.2.27:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by ESs5 in Experimental group (Transient (tr), Post-transient (fr), and Aspiration (as)).

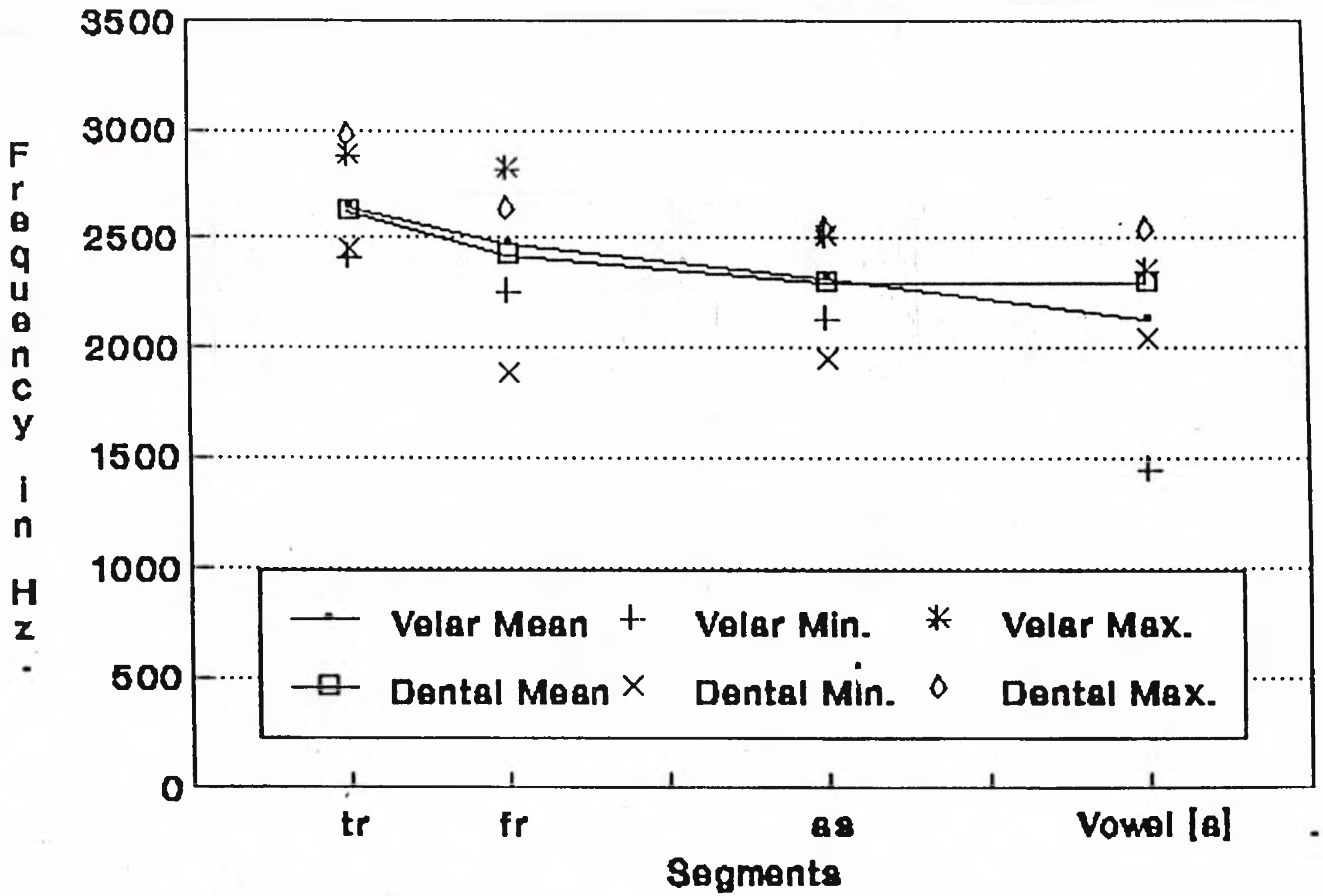

Fig. 4.2.28:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by ESs6 in Experimental group (Transient (tr), Post-transient (fr), and Aspiration (as)).

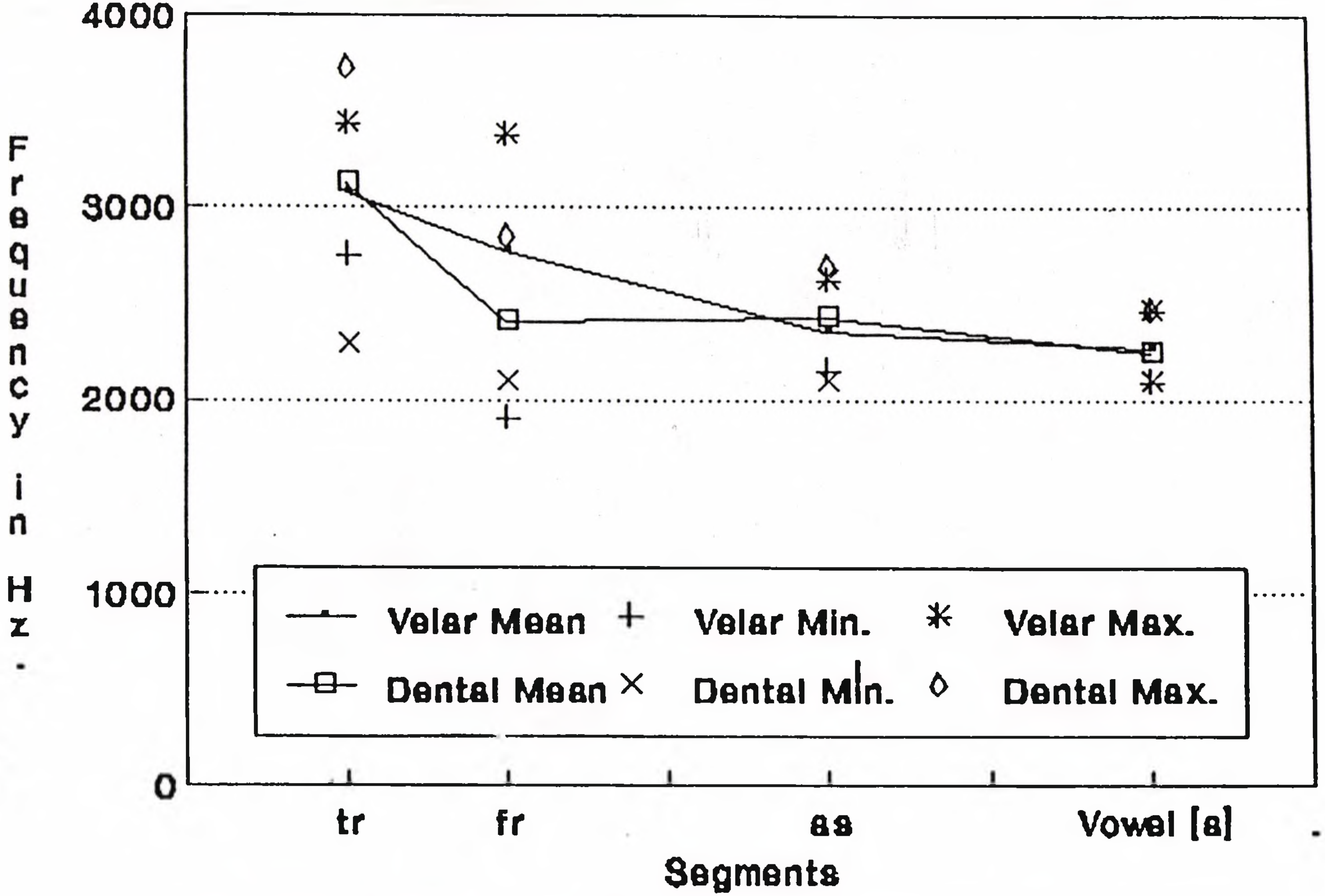

Fig. 4.3.29:- The mean and spread of F2 related peak in various segments of velar and dental aspirated initial minimal pair spoken by ESs7 in Experimental group (Transient (tr), Post-transient (fr), and Aspiration (as)).

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Table 4.2.29b:- Mean and SD of **F2tr-F2[a]** in the velar and dental initial minimal pairs for subjects with and without velar fronting. The values in parenthesis indicate the number of negative values.

Ss	/kʰali/ Mean(Hz)	SD	/t̠ʰali/ Mean(Hz)	SD
ESs1.	572.4	250.5	330.8(2)	426.2
ESs2.	563.3	437.2	462.6(1)	355.8
ESs3.	765.5	522.4	756.3	414.6
ESs4.	483.0	389.0	699.8	486.0
ESs5.	574.8	236.8	664.7	223.1
ESs6.	509.3	364.1	317.3(1)	256.3
ESs7.	803.1	220.1	884.4	497.7
Group	610.2	364.4	588.0(4)	427.5

Tables 4.2.30:- Mean and SD of F2tr-F2fr and F2tr-F2[a] in the velar and dental initial minimal pairs for subjects with and without velar fronting.

Type of Measure	/kʰali/		/t̠ʰali/	
	Subjects with:-			
	Control Group I Mean (SD)	Expt. Group I Mean (SD)	Control Group I Mean (SD)	Expt. Group I Mean (SD)
F2tr-F2fr	3.7 (166.5)	226.5 (387.5)	249.7 (453.0)	233.5 (463.5)
F2tr-F2[a]	39.3 (216.9)	610.2 (364.4)	678 (488)	588.0 (427.5)

No significant difference was obtained for /t̠ʰalI/ spoken by control group and both members of the minimal pair by subjects with velar fronting.

4.4.2.2 <u>Separate analysis of acoustic data obtained from the output of subjects ESs8 and ESs10:</u>-

Subject ESs8 was twenty years old and had had some sessions of speech therapy at the time of audio-tape recording. A mean fundamental frequency of 194.2 and SD of 5.8 was obtained with no significant difference for the minimal pair for F0 values. The mean and SD of the F2 related peak measured in the average LPC spectra of different segments of the consonant and the F2 of vowel [a], for the minimal pairs is available in Table 4.2.31. On applying the Mann-Whitney test, the Wilcoxon Rank Sum Test and the Scheffee test to the data no significant differences in the means for these acoustic parameters were obtained.

<u>Table 4.2.31</u>:- The mean and SD of F2 of vowel [a] and F2 related peak measured in the average LPC spectra of different segments in /k^halI/ and /$\underline{t}^h$alI/ attempted by **subject ESs8**.

Acoustic Measure	Velar Mean	Velar SD	Dental Mean	Dental SD
F2tr (Hz)	2287.6	399.3	2275.0	237.0
F2fr (Hz)	2181.7	273.4	2057.6	237.7
F2as (Hz)	1859.4	257.2	1817.3	131.7
F2[a] (Hz)	1756.2	56.6	1715.8	80.0

The mean and SD of intensity measures for /k^halI/ and /$\underline{t}^h$alI/ spoken by subject ESs8 are given in Table 4.2.32.

Table 4.2.32: The mean (dB), SD, of intensity related variables measured in the LPC average spectrum various segments of in /k^{h}alI/ and /t̪^{h}alI/ attempted by **subject ESs8**. (Generally ten values contributed to the mean per subject for each stimulus word . In case of measurement difficulties this number was less. The values enclosed in brackets indicate the number contributing to the mean.)

Acoustic Measure	Velar Mean(n)	SD	Dental Mean	SD
ILtr(dB)	10.8(09)	4.7	6.3(10)	2.7
IHtr(dB)	1.8(10)	5.8	-5.4(10)	3.7
ILfr(dB)	9.0(10)	3.8	7.2(09)	3.0
IHfr(dB)	-1.9(10)	5.0	-5.1(09)	3.6
ILas(dB)	7.7(10)	3.2	9.8(09)	4.2
IHas(dB)	-3.9(10)	2.7	-4.0(09)	2.3

The means and SDs of duration of the transient, aspiration, vowel [a], VOT, and the entire word are given in table 4.2.33. On applying the Mann-Whitney, the Wilcoxon Rank Sum Test and the Scheffee test to the data significant differences between the means for duration of transient, VOT, and aspiration were obtained. However, conflicting results were obtained in the case of duration of vowel [a] and the entire word with Scheffee indicating a significant difference and the non-parametric test otherwise. Hence, the differences were not considered to be significant for these measures.

Table 4.2.33:- The mean and SD of **durational measures** of various segments of /k^halI/ and /$\underline{t}^h$alI/ attempted by **subject ESs8**.

Acoustic Measure	Velar Mean	Velar SD	Dental Mean	Dental SD
Dtr (ms)	13.2	2.9	10.7	2.4
VOT (ms)	104.6	16.0	62.0	17.0
D [a] (ms)	127.8	62.2	82.1	24.4
Dwrd (ms)	451.5	60.0	391.4	60.7
Das (ms)	91.4	14.4	51.3	17.1

The mean and SD of **F2tr-F2fr** and **F2tr-F2[a]** for subject ESs8 are given in table 4.2.34. The difference in mean F2tr-F2fr and F2tr-F2[a] for the two words was not significant as indicated by the Mann-Whitney, the Wilcoxon Rank Sum Test and the Scheffee tests for significance between mean.

Table 4.2.34:- The mean and SD of **F2tr-F2fr** and **F2tr-F2[a]** for /k^halI/ and /$\underline{t}^h$alI/ attempted by subject ESs8. The values in parenthesis indicate the number of negative values.

Acoustic Measure	Velar Mean	Velar SD	Dental Mean	Dental SD
F2tr-F2fr(Hz)	105.9(1)	323.7	217.4(4)	219.2
F2tr-F2[a](Hz)	531.4(4)	415.0	559.2(1)	247.6

Subject ESs10 mainly produced unaspirated plosives, and so post-transient and aspiration measures were not appropriate. A high mean F0 of 411.8 Hz (SD = 36.9) was obtained. On applying the Mann-Whitney test, the Wilcoxon

Rank Sum Test and the Scheffee test to the data no significant differences in the means for any of these acoustic parameters including F0 were obtained (Table 4.2.35).

Table 4.2.35:- The mean and SD of various acoustic measures obtained from /k^halI/ and /$\underline{t}^h$alI/ attempted by subject ESs10.

Acoustic Measure	Velar Mean	Velar SD	Dental Mean	Dental SD
F2tr (Hz)	2846.8	477.5	2684.3	430.6
F2[a] (Hz)	2318.8	103.9	2397.6	198.1
ILtr* (dB)	6.3 (3)	2.1	5.8(6)	2.4
IHtr* (dB)	2.1 (4)	2.3	-.4(8)	3.2
Dtr (ms)	8.5	1.1	8.8	3.2
D [a] (ms)	106.2	37.0	115.2	13.3
Dwrd (ms)	522.3	22.6	536.3	48.1
F2tr-F2[a]** (Hz)	528.0(6)	533.9	286.7(7)	415.6

(Note:- * The parameters where there were problems in measurement such that the values contributing to the means were less than ten. The actual values contributing to the mean are given in brackets.
** The values in parenthesis indicate the number of negative values in the data.)

Finally, no acoustic measurement of the output of subject ESs9 was attempted as an entirely different approach was required for defining the segments and acoustic variables , for example VOT in voiceless vowel, duration of vowel, duration of aspiration etc.

4.4.2.3 <u>Application of Discriminant Analysis to data obtained from CSs1 to CSs5 and ESs1 to ESs7:-</u>

The Discriminant Analysis was applied to the data to study the differences between the minimal pairs with respect to all acoustic measures simultaneously. The intensity related measures of ILtr, ILfr, ILas, IHtr, IHfr, and IHas were not included in this analysis due to missing values related to methodological problems explained earlier (page no.164). The data obtained from subjects in control group I and experimental group were analysed separately.

1) <u>Control group I :-</u>

The pooled with-in groups correlation matrix obtained for normally speaking subjects reveals that F2 related peaks in various segments tended to correlate with each other (Table A3.1.1 in Appendix III). Further, Fo showed correlation with F2 of vowel and F2as. VOT measures showed positive correlation with F2as. In general these correlations are not very high.

Wilks Lambda (U-statistic and univariate F(1,75) ratio obtained for this group are given in Table A3.1.2 (Appendix III). Significant differences ($p<.001$) level were observed for F2tr, F2fr, F2as VOT, Das, and F2 of vowel [a]. The smaller the value, the greater the difference. This indicates that within group variability is small compared to the total variability and that the group means differed significantly.

The standardised canonical Discriminant function coefficients and the Structure coefficients provides some information on the relative importance of the variables contribution to the Discriminant score (A3.1.3 and A3.1.4 in Appendix III). However the structure coefficients provide a better idea of each variable's contribution to the Discriminant score since they are simple bivariate correlations. The order of importance is similar to those obtained from Wilks' lambda (Appendix III).

From table 4.2.36 it is clear that the variables could separate velars and dentals spoken by children with no production errors, at a very high level of accuracy with velars at 100.0% and dentals at 92.0%. The obtained Wilks' Lambda of .3132 from the canonical Discriminant functions is significant beyond the .001 level indicating that the obtained difference in centroids would be obtained once in a thousand samples by chance alone (Table A3.1.5 in Appendix III).

<u>Table 4.2.36</u>:- Classification of velars and dentals based on Discriminant scores for data from output of subjects in group I.

Actual Group		No. of Cases	Predicted Group Membership 1	2
Group Velar	1	50	50 100.0%	1 0.0%
Group Dental	2	50	4 8.0%	46 92.0%

Percent of "grouped" cases correctly classified: 96.0%

2) **Experimental group :-**

The pooled with-in groups correlation matrix for the data obtained from the experimental group revealed that VOT correlated highly with duration of the aspiration segment. The F2 of vowel [a] correlated with the F2 related peak measured in the aspiration segment. In general the variables are not very well correlated (see Table A3.2.1 in Appendix III).

The high value of Wilks' Lambda obtained for this data indicates that within group variability is similar to total variability and that the group means for the variables do not differ significantly in general. This observation derives from the nature of Wilks' Lambda, namely that the smaller the value obtained, the greater the difference between the means (see Appendix III, Table A3.2.2). Classification of velars and dentals based on Discriminant scores for data from the experimental group was at chance (Table 4.2.37 and Fig. 4.2.30).

Table 4.2.37:- Classification of velars and dentals attempted by subjects with velar fronting based on Discriminant scores .

Actual Group		No. of Cases	Predicted Group Membership 1	Predicted Group Membership 2
Group Velar	1	70	36 51.4%	34 48.6%
Group Dental	2	70	31 44.3%	39 55.7%

Percent of "grouped" cases correctly classified: 53.57%

Figure 4.2.30:- The histogram of Discriminant scores for the two types of words attempted by the velar fronting subjects. Symbol 1 represents Velars and 2 represents Dentals in the plot.

```
              Canonical Discriminant Function 1
     8 E                                         E
       3                                         3
       3                                         3
       3                                         3
     6 E                                         E
       3                                         3
       3                   2                     3
       3                   2                     3
     4 E              2  212    2  2             E
       3              2  212    2  2             3
       3          1  11  2112   2  22            3
       3          1  11  2112   2  22            3
     2 E          1  112 11121 22 222            E
       3          1  112 11121 22 222            3
       3         11  11111111121221221   2 2     3
       3         11  11111111121221221   2 2     3
        XDDDDEDDDDEDDDDEDDDDEDDDDEDDDDEDDDDEDDDDX
      Out -3.0 -2.0 -1.0   .0  1.0  2.0  3.0   Out
  Class   1111111111111111111122222222222222222222
Centroids                  1      2
-----------------------------------------------------
```

4.5 Discussion

The focus of experiment-I was to ascertain whether the following were true or not.

1) Do children with velar fronting consistently substitute a dental plosive for the target velar sound?

2) Do children who front velars in their production maintain acoustic differences in their velar error productions and replacing apical-lingual stop consonant?

3) Are there acoustic differences in word initial velar and apical-lingual stop contrasts attempted by children fronting their velars, and children with no production errors?

4.5.1 Evidence from perceptual analysis:-

The perceptual analysis indicates that subjects with velar fronting often substitute dental initial sound. However, the substitution pattern is not as consistent as expected. From a total of 100 tokens of /k^{h}alI/ and /t̪^{h}alI/ each attempted by velar fronting subjects, 160 tokens (80%) were heard distinctly as /t̪^{h}alI/ (Table 4.2.A page no 128). One would expect that all attempted /t̪alI/s would account for a large share of this figure. However, this was not true as 75% of /k^{h}alI/s and 85% of /t̪^{h}alI/s were heard as /t̪^{h}alI/.

From Table 4.2.A (page no 128), it may be observed that, only subjects ESs1, ESs3 and ESs4 realised all initial velars as aspirated voiceless dental plosive. However, the output for the rest of the 7 subjects does not indicate such consistency. Of the remaining 70 recorded tokens of /k^{h}alI/, 53 tokens alone were transcribed as having initial /$\underline{t}^h$/ consonant. The remaining 17 were transcribed as being voiceless dental fricatives, aspirated voiceless retroflex stops, glottal fricatives, unaspirated voiced dental plosives, and unaspirated labialized dental plosives. In the case of subject ESs2, one of the tokens were transcribed as containing a aspirated voiceless velar plosive. This variety of replacing phoneme is missed in the clinical context.

Evidence from detailed and careful perceptual analysis indicates that there is considerable variation in the nature of the replacing sound. It was observed that the output of all 10 attempts of /$\underline{t}^h$alI/ by ESs1, ESs3 and ESs7 were transcribed as /$\underline{t}^h$alI/. Of the other 70 /$\underline{t}^h$alI/ tokens, from the remaining seven subjects, 57 tokens were transcribed as having initial /$\underline{t}^h$/. The remaining 13 tokens were transcribed as dental fricatives, aspirated voiceless retroflex stops, and 10 tokens from subject ESs8 as being not very distinct initial /$\underline{t}^h$/ consonant. Thus it appears that some subjects who front velars, also show inconsistency in their production of the apical sound which is perceived to be used for substitution. Furthermore, while producing the already mastered initial consonant in /$\underline{t}^h$alI/, there was a tendency to substitute other apical sounds such as retroflex plosive (Table 4.2.A page no 126). The poor inter-transcriber reliability among subject ASs2, ASs3 and ASs4, indicates the fallibility of the human ear in analysing speech. These inter-transcriber reliability values reflect where transcribers agreed that the initial phoneme was a /$\underline{t}^h$/, /k^h/, and `distorted'. The term distorted is used to refer to instances where adult transcriber indicated that the initial phoneme was `velar-like', `dental-like' or unable to decide. The relatively greater disagreement in /k^halI/ (52%) as compared to /$\underline{t}^h$alI/ (72%), may reflect the variation in the listeners skill in transcribing speech sounds not part of the phonemes of their language.

There appears to be some evidence to indicate that an individual's transcription skill depends upon the native language of the listener. Among the less experienced listeners, ASs2 and ASs3 were native speakers of Hindi, while ASs4 was a native speaker of Telegu. It is interesting to observe that subject ASs2, and ASs3 perceived 80% and 86% respectively, of the minimal pairs as /$\underline{t}^h$alI/, compared to ASs4 who perceived only 68% as /$\underline{t}^h$alI/. However this evidence needs to be systematically investigated prior to drawing conclusions.

The performance of less experienced listeners may perhaps be compared to the analysis done in the clinical situation where all of the subjects in the experimental group had been observed to substitute /$\underline{t}^h$/ for /k^h/ in all conditions except ESs8. The variability, as indicated by the perceptual analysis, may perhaps be missed by the practicing Speech-language pathologist due to constraints on time and transcription skills. Acoustic analysis which supplemented perceptual analysis appears to provide insight into the nature of production difference observed in perceptual analysis.

__4.5.2 Evidence from Acoustic analysis:-__ Due to problems in employing acoustic analysis technique routinely used in analysing stop consonants, it became necessary to develop a procedure that would be useful with analysing abnormal child data. Specific acoustic measures were made at different segments of the initial CV syllable totalling 17 acoustic measures of velar and dental aspirated plosives spoken by children. It was generally observed that in the aperiodic portion, tracking of F3 was much more difficult than of F2 and F1. Although information on F3 values was desirable from its relevance for making prediction about place and tongue movement, no attempt was made at measuring F3 because of these difficulties. The results appear to indicate that children with no production difficulty maintain significant difference in a number of acoustic parameters (Table 4.2.38).

As one to one articulatory gesture to acoustic mapping is not always possible, an attempt was made to create an `acoustic production profile' of velar and dental aspirated voiceless plosives which could be used for comparing the samples of children with velar fronting (Table 4.2.39).

Table 4.2.38:- The mean and level of significance for difference between the mean for /kʰalI/ and /t̲ʰalI/ spoken by CSs1 to CSs5.

Acoustic parameters	Mean /kʰalI/	Mean /t̲ʰalI/	Significance level for various sources of variation: Subj.	Min.pair	Interaction
F2tr	1963	2680	.001	.001	.001
F2fr	1959	2452	.001	.001	NS
F2as	1967	2272	.001	.001	.001
F2[a]	1924	2030	.001	.001	.05
Dtr	8.8	7.9	.001	.05	NS
Das	73.8	59.8	.001	NS	NS
VOT	88.3	63.1	.001	.001	NS
D[a]	105	109	.001	NS	.05
Dwrd	631	615	.001	NS	NS
Fo	298	301	.001	NS	NS
F2tr-F2fr	4.0	250.		.001*	
F2tr-F2[a]	39.3	678.0		.001*	

(Note:- *Indicates significance level for difference in mean obtained from t-test. Rest are from ANOVA)

Table 4.2.39:- The mean and level of significance for difference between the mean for /k^h^alI/ and /t̠^h^alI/ spoken by ESs1 to ESs7.

Acoustic parameters	Mean /k^h^alI/	Mean /t̠^h^alI/	Significance level for various sources of variation: Subj.	Min.pair	Inter-action
F2tr	2804	2818	.001	NS	NS
F2fr	2758	2584	.002	NS	NS
F2as	2371	2392	.001	NS	NS
F2[a]	2194	2230	.001	NS	NS
Dtr	12.4	12.3	.001	NS	NS
Das	61.2	64.2	.001	NS	.001
VOT	73.8	76.5	.001	NS	.001
D[a]	138.0	123.0	.001	.02	NS
Dwrd	627.0	602.0	.001	.05	NS
Fo	370.0	368.0	.001	NS	NS
F2tr-F2fr	227.0	234.0		NS*	
F2tr-F2[a]	610.2	588.0		NS*	

(Note:- *Indicates significance level for difference in mean obtained from t-test. Rest are from ANOVA)

On comparing table 4.2.38 and table 4.2.39 it is obvious that as a group the velar fronting subjects did not maintain statistically significant acoustic differences in most acoustic parameters measured for the minimal pair. However, the results indicate that some subjects did maintain significant acoustic differences for some of the parameters (Table 4.2.40).

Table 4.2.40:- The acoustic parameters for which significant difference in mean for the minimal pair were obtained for each of the subjects in the Experimental group.

Subject	Acoustic difference for the minimal pair
ESs1	Longer [a] for velars Longer velar word
ESs2	Longer [a] for velars
ESs3	Longer [a] for velars Longer velar word Longer Aspiration for velars Longer VOT for velars
ESs4	Longer [a] for velars Longer velar word Shorter Aspiration for velars
ESs5	Longer [a] for velars Longer velar word
ESs6	Longer [a] for velars Longer velar word
ESs7	Longer [a] for velars Longer velar word Higher F2fr
ESs8	Longer Aspiration for velars Longer VOT for velars Longer transient duration for velars
ESs9	Problems in analysis
ESs10	Nil

4.5.3 Nature of Acoustic differences in /k^halI/and /t^halI/ spoken by children with no output error and with velar fronting:-

One of the striking features of the findings in normal data is the subject variability for both frequency and time related measures. The findings are in agreement with Hewlett's observation (1988), that highest peak frequency measures and VOT in velar and alveolar plosives spoken by two normal children has greater within speaker variance than those found in adult production. The variability observed in Hewlett's finding appears to indicate that it is more typical of child data than of adult data.

Several factors separately or together, could be contributing to subject variability in child data. Firstly, although the subjects ages ranged only from 5;2 to 5;8 years, they were actually at different stages of developmental maturity. Secondly, fundamental frequencies (F0) were different with concomitant effects to the formant related measures. Thirdly, the children spoke at different tempi so duration related measures were effected. Significant differences between subjects were observed for both F0 and word length. From Figure 4.2.15a. (page no.204) it is clear that the subjects formed two distinct groups for F0, while in the case of word length no such grouping was observed (Figure 4.2.14a in page no.197). The lack of significant differences for the minimal pair effect and interaction effect indicates that word length and F0 would not be confounding variables while comparing within subject velar and dental production. The results suggest the need to obtain large within subject samples as well as across subject samples. Such a sampling strategy would permit a single case study approach and enable findings to be related across a number of subjects.

Ia. F2 related peak and energy distribution in subjects with no output error:- As predicted by the source filter theory of speech production, an increase in high frequency energy mainly characterised dentals in this study. The increase was observed both in transient and post-transient segments for the F2 related peak (Fig. 4.2.3a and 4.2.4a page no 140-41) and in the energy peak between 3kHz and 4kHz (Fig. 4.2.8a and 4.2.9a page no 159-161). The high F2 related peak observed in this data is in agreement with Fant's (1973) observation of Swedish dentals produced by adults but in contradiction to Lahiri et al's(1984) findings for both Malayalam and French dentals for the initial 26 ms average spectrum. As predicted, the high frequency emphasis gradually decreases as the oral cavity becomes more open for aspiration and vowel [a]. The F2 related peak decreases to mid-frequency range (more markedly for dentals than velars) when vowel [a] is reached, the differences in F2 related peak for velars and dentals reduce, although statistically significant differences continue to exist (Fig.4.2.3a, 4.2.4a, 4.2.5a and 4.2.6a page no 140 to 143). The difference in the F2 related peak for velars and dentals at aspiration and vowel presumably reflects co-articulation. A similar effect is observed in the high frequency peak between 3 kHz and 4 kHz (IH values), which also reduce along with a marked increase in anti-resonance between F2 and 3 kHz (IL values) (Figure 4.2.8a and 4.2.9a page no 179-181). It could be argued that the greater similarity in the /k^h/ and /$\underline{t}^h$/ spectra in aspiration was due to the larger segment duration used for computing average LPC spectra, compared to that for transients and post-transient segments. Although a downward trend in the frequency of F2 related peak was observed in aspiration, it was not dramatic. Visual inspection of spectrograms indicated that the F2 related peak in aspiration was fairly constant in time (Fig.4.2.1a, 4.2.1b, 4.2.1c, 4.2.1d, 4.2.1e, 4.2.1f, and 4.2.1g page no 114 to 120). So this factor would be expected to minimally effect the values obtained during LPC averaging. However, it was observed that often the initial portion of aspiration had greater high frequency energy than the latter region for dentals. This is in agreement with the findings of Lahiri et al (1984) and Kewley-Port (1982) that for apical plosives high frequency energy persists for a longer time than it does for bilabials or velars. Although several researchers have predicted an increase in high frequency energy for dentals, and an increase in mid-frequency energy for velars in the average spectra, few have explained the relationship in energy patterns below 3 kHz and between 3 and 4 kHz in the two categories of sounds. At this stage no speculations will be made about this feature. The presence of this feature in other vowel environments needs to be verified, along with its relevance as a place of articulation perceptual cue.

The Formant 2 transition for velars has been described as descending when the consonant is followed by a back open vowel, as is the case in this study. About 44% of velars were found to have F2 related peak in the transient lower than the F2 of the following vowel (table. 4.2.29a page no.217). Some subjects (CSs1 and CSs3) appear to have this feature more often than others. None of the dentals had this feature. When F2tr-F2[a] is negative it appears as though the point of release is sufficiently far back to require the tongue to move forward to reach the configuration for the vowel [a]. Such a feature has not been reported for adult productions and may be expected in aspirated uvular stops.

Another interesting feature observed was in the F2tr-F2fr values in table 4.2.28a (page no.217). Once again, one would assume this value to be always positive. However, both velars and dentals appear to have negative values, with velars (34%) having more than dentals (18%). If the F2 related peak is taken to reflect tongue movement, then the negative values may be interpreted as reflecting a slightly forward tongue movement after release to the gradual descent to the vowel position. It is tempting to speculate that this could be residual from the tongue thrust behavior associated with sucking and swallowing patterns in infancy.

It may be predicted from co-articulatory influences that the following vowel would be influenced by the consonant preceding it. In the case of velars the tongue may assume a slightly back posture for back vowels. So higher F2 value was expected for vowel following dental compared to velars. Although the mean increase of 117.6 Hz. for F2 of [a] was found to be significant, from Fig.4.2.6a (page no.143) it is clear that the main contribution to this finding was the data of CSs4 and CSs5 whose dental F2 [a] increased by an average of 192 Hz and 231.4 Hz respectively. From the pattern of movement of the F2 related peak from the transient to Vowel [a] in Fig 4.2.18 to 4.2.22 (page no.212-216) it appears as if in subjects CSs1, CSs2 and CSs3 consonant production minimally influenced F2 [a]. One is tempted to speculate that the findings indicate for subjects CSs1, CSs2, and CSs3 that the co-articulatory influence of the consonant ended at aspiration due to the nature of contrast in aspiration in the Indoaryan languages in question. It would be interesting to observe if such subject variation is observed in languages where a number of contrasts in aspiration is not present.

<u>Ib. F2 related peak and energy distribution in subjects with velar fronting :</u>- Evidence from the F2 related peak measures indicates that /$\underline{t}^{h}$alI/ attempted by the experimental group was significantly different from that attempted by control group I, being significantly higher. Higher F2 related peak may be attributed to three factors, namely:-

a) a more forward point of articulation, and/or

b) a smaller vocal tract,

The experimental group had significantly higher F0 values. One is tempted to speculate that this higher F0 reflects anatomical immaturity of the larynx. On the other hand a higher F0 may be the result of anxiety on the part of the experimental group.

Usually the larynx is pulled upwards in order to produce s higher pitch. This may have shortened the vocal tract resulting in higher F2 related peak and formant two. However, as formant two largely reflects front cavity resonance, it is doubtful whether raising of the larynx would have effected the point of articulation. Further investigation needs to be done in order to ascertain the nature of F0 and spectral measures in phonologically disordered children.

In terms of Formant transition related measures of F2tr-F2fr and F2tr-F2[a], both values obtained for the output of experimental group indicate that they were more like the values obtained for the dental targets produced by the control group I (table 4.2.28b and 4.2.29b page no.220,228). Since transitions are one of the important perceptual cues for adults, these tokens would be perceived as an apical plosive. On examining the negative values, for F2tr-F2fr, it may be noted that there were more negative values for the fronted /k^{h}alI/(20%) and target /t̲^{h}alI/(27%), compared to those obtained for /t̲^{h}alI/ of control group I(18%). This indicates that the transients did not always slope downward from the transient to the post-transient segment. It would be interesting to observe if such negative values correlate with palatographic or video-fluroscopic observation of tongue thrust during production of lingual plosives. In the more gradual transition, reflected by F2tr-F2[a], negligible negative values were noted which is similar to those observed for /t̲^{h}alI/ spoken by control group I.

IIa. Durational Measurements (VOT, Dtr, Das, D[a]) in subjects with no output error:-

i. Voice onset time:- As expected, significantly higher VOT values were observed for velars than for alveolars. This acoustic measure has been observed to separate reliably velars from other places of articulation. Kewley-Port (1982) observed that VOT was very effective in classifying voiced plosive place of articulation (88%) and appears not to be effected by vowel context. Kewley-Port points out that, as a "perceptual cue" its importance appears limited, as the auditory system is incapable of discriminating small VOT differences during continuous speech. Since their data consisted of voiced plosives this may be true. Zlattin and Koenigsknecht (1976) reported a mean VOT of 80.2ms for the velar in `coat' and 68.7ms for the alveolar in `time' for English speaking 6year olds. A similar VOT of +91.6ms and 61.9ms for velars and alveolars was reported by Macken and Barton (1978) for the newly acquired voicing contrast by 2;1 year olds. In general the VOT obtained for control group I in the present study are comparable.

In the case of voiceless aspirated plosives a significant mean difference of 25.2 ms was obtained for velars and dentals and may, therefore be relevant to place cueing in this class of sounds. Furthermore, from the point of view of production analysis , VOT appears to be an invaluable parameter for predicting whether a voiceless aspirated plosive has been `backed' or not.

ii. <u>Duration of transients:</u>- The transient has been described by Fant (1973) as "the response of the vocal tract to the pressure release, exclusive of any turbulence effects." Fant,(1973). Although the frequency spectrum of the transient is well known to enhance perception of differences between place of articulation, the duration of the transient has gained the attention of very few researchers. Lahiri et al (1984) observed that only 54% of the Malayalam and French dental stops showed greater energy in the 'burst' compared to bilabial. It is assumed that the 'burst' refers to the transient portion, as their analysis was conducted on the initial 10ms of the waveform. However, there was no durational measurements of the initial release. In the present study, the mean dental transient for all subjects (except CSs3) is consistently shorter than those for velars (Fig.4.2.10a page no.179). As mentioned earlier, this is in agreement with observation of other researchers (Fant, 1973, Hawkins, 1986ab, Hawkins & Stevens, 1987). It would be interesting to correlate this measure with double articulation (apical + tongue body raising) which is often suspected in the attempted production of velars by some velar fronting children.) Although the duration of transient may not be significant as a perceptual cue (considering its briefness), it may be relevant for predicting, analysing and interpreting articulatory dynamics.

iii. <u>Aspiration and vowel variants:</u>- Aspiration in Hindi and Marati is contrastive in all plosives and some affricates, and hence it was expected that it would be more prominent in duration than in Swedish. Although the duration of the aspiration segment is not reported in Fant's study (1973), on comparing the mean duration of aspiration (73.8 ms and 58.8 ms) obtained in this study to their VOT value of 140 ms and 120 ms for velars and alveolars respectively, it may be deduced to be shorter. Perhaps this is due to our sample being from children who also had considerably shorter VOTs.

<u>IIb. Durational Measurements (VOT, Dtr, Das, D[a]) in subjects with velar fronting:-</u>

Several interesting features about attempted velar and dental words by velar fronting group emerged from durational measures. The subjects, individually and as a group maintained significantly longer following vowel for /k^{h}alI/. It was also observed that velar initial words were generally longer too. Although subjects with velar fronting as a group had longer following vowel than control group I, the total time taken to say the minimal pair was the same for the two subject groups. Furthermore, the longer vowel [a] duration cannot be attributed to a trend for the experimental group to take more time in saying the stimulus words, as word duration measures indicate to the contrary. Firstly, there was no significant difference between the two groups of subjects for word duration. Secondly, it may be observed from the mean word duration in table 4.2.25 (page no.203) that the experimental group took the longest time to say /k^{h}alI/ but were the quickest in saying /$\underline{t}^h$alI/. The experimental group appear to be shortening the second syllable rather than the aperiodic portion of the initial consonant in order to take the same time to say the words as a whole as in the case of normal children. On the other hand duration of aspiration, transient and VOT were generally found to be similar for the two words, except for adult subject ESs8 who maintained significant differences for all these parameters. The longer vowel [a] and word duration of attempted /k^{h}alI/ cannot be attributed to poor coordination of less "mature" production skills.

The larger transient durations in samples from the experimental group may be indicative of slower release of the oral air pressure. The longer transients may have resulted in the trained listener marking a number of tokens as "not distinct" or as fricatives. Further analysis and investigation would be required prior to arriving at a conclusion.

Detailed acoustic analysis of production dynamics appears to indicate that some of the subjects who fronted velars may be maintaining statistically significant acoustic differences in their output for /k^{h}alI/ and /$\underline{t}^h$alI/ (Table 4.2.39 and 4.2.40 page no.242-43). From the results it is apparent that subjects ESs3 and ESs4 maintained acoustic allophonic differences in the minimal pairs in terms of durational differences in aspiration and VOT. Furthermore, as a group, subjects ESs1 to ESs7 maintained significant difference between the two target words in terms of vowel length with a larger duration for vowel [a] in /k^{h}alI/ than in /$\underline{t}^h$alI/. The same is true in the case of duration of the entire word. These findings are in agreement with earlier findings that some subjects with output errors, maintain significant acoustic differences in acoustic parameters, which are not the same features which are the perceptual cues for that class of sound in the case of adults (Weismer, 1984; Hewlett, 1988,Ryall, 1989, Forrest et al, 1994). However,it is not clear whether this is due to the child's attempt to make a distinction and failing in the process, or whether it is a deliberate attempt to maintain this durational difference which is viewed as sufficiently "contrastive" by the child. Tests of perception may clarify the issue.

The 96.0% success rate in classifying velars and dentals based on Discriminant analysis of all the acoustic variables is indeed promising. However the Discriminant analysis was not so successful with data from velar fronting group. It may be argued that the high classification obtained for the normal group was obtained due to the single vowel environment compared to other studies which attempted a wider vowel context (Hewlett, 1988; Young and Gilbert, 1989; Weismer et al, 1990). However, the `Stevens-Blumstein 'template approach when applied to the same data was not so successful. This also emphasises the need for researchers to establish acoustic measures which reflect production dynamics in both children and adults rather than those which reflect only perceptual cues for adult contrasts. Furthermore, although Discriminant Analysis indicates that transient related variables were the main contributors to velar and dental contrasts Analysis of Variance applied to various acoustic data indicates that other measures are also important for production analysis in normal children.

It may be concluded that some children who front velars do maintain consistent acoustic differences between their dental velar error productions and dental for dental stop consonants, that is [$\underline{t}^h$] for target /k^h/ is not the same as [$\underline{t}^h$] for /$\underline{t}^h$/. Variation in the production of the apical stops in children who backed stops have been reported by Gibbon, Dent, and Hardcastle, 1993. Thus the practicing Speech-language pathologist needs to focus not only on velar production but also on the phoneme that is perceived as being substituted.

-oOo-

Experiment II: Speech sound perception in velar fronting children.

5.1 Introduction:

Results of experiment I (chapter IV) indicated that at least four subjects with velar fronting, maintained statistically significant differences in more than three acoustic parameters (table 4.2.40 in page no243). Furthermore, seven of the subjects maintained a significantly longer vowel [a] and word length for attempted /k^halI/. Acoustic analysis alone is not sufficient to ascertain whether these differences are important to the velar fronting child. Experiment II attempts to ascertain the nature of speech sound perception in velar fronting subjects. It attempts to answer the following questions:-

1) Do subjects with velar fronting auditorily contrast velar and dental initial words spoken by adults?

2)Do subjects with velar fronting perceive all their attempted velar initial words as dental initial words?

3) Is there a significant difference between the identification score obtained by subjects with velar fronting and subjects with no production error, while listening to velar and dental initial words attempted by velar fronting

subjects?

4) Are there significant differences in identification scores for misarticulators, normal children and adult while listening to minimal word pairs containing velar and apical stops with varying amounts of burst, aperiodic energy and formant transitions?

The study will test the following null hyypothesis:-

1) Subjects with velar fronting perform at chance while identifying`velar and dental initial words spoken by an adult speaker.

2) Subjects with velar fronting identify all their velar words as dentals while listening to their own audio recorded tokens of velar and dental initial words.

3) There is no significant difference between subjects with and without velar fronting while identifying velar and dental initial words spoken by velar fronting subjects.

4) Subjects with velar fronting perform at chance while identifying their own audio reorded velar and dental initial words with varying amount of initial consonant segmented.

subjects?

4) Are there significant differences in identification scores for misarticulators, normal children and adult while listening to minimal word pairs containing velar and apical stops with varying amounts of burst, aperiodic energy and formant transitions?

The study will test the following null hyypothesis:-

1) Subjects with velar fronting perform at chance while identifying`velar and dental initial words spoken by an adult speaker.

2) Subjects with velar fronting identify all their velar words as dentals while listening to their own audio recorded tokens of velar and dental initial words.

3) There is no significant difference between subjects with and without velar fronting while identifying velar and dental initial words spoken by velar fronting subjects.

4) Subjects with velar fronting perform at chance while identifying their own audio reorded velar and dental initial words with varying amount of initial consonant segmented.

5.2 Experimental procedure:-

5.2.1 Subjects:-

Subjects included children allocated to both experimental and control groups.

i) Experimental group:-

Ten subjects (7 boys, 2 girls and one women of 20 years) with velar fronting participated in this study. The children who fronted velars had a mean age of 5.7 years, which ranged from 5;2 to 7 years. They are referred to as ESs1 to ESs10. All the subjects in this experiment had participated in experiment II reported in chapter IV (See chapter IV, page 94,109 for details of experimental group selection).

ii) Control group :-

Two control groups were included:-

Control group I consisted of ten children with normal speech, cognitive, language and hearing skills matched in age, sex and mother tongue to the subjects in the experimental group. Five of these subjects had participated in experiment II reported in chapter IV and referred to as CSs1 to CSs5.

Control group II consisted of one trained adult listener ASs1 (See chapter IV, page 109, for details).

5.2.2 **Speech stimuli:-**

Two minimal pairs meaningful to both Marati and Hindi languages were selected (See chapter IV, page 95,109 for detailed justification and selection criteria). The following contrasts were included from the Marati and Hindi languages:-

Marati		**Hindi**	
/k^halI/[1]	\`down'	/k^halI/	\`empty'
/$\underline{t}^h$alI/	\`plate'	/$\underline{t}^h$alI/	\`plate'
/palI/	\`lizards'	/palI/	\`island'
/halI/ [2]	\`green worm'	/halI/	\`green worm'

Line drawings representing words in the child's first language were selected for all activities for each child (Appendix IV).

5.2.3 **Perception task :-**

The perception task was the same for all the perception tests. The stimuli differed in each of the tests. A four alternative forced choice picture identification task (4IAX) was employed in all the perception tests. The 40 stimulus words were randomly presented through headphones

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1.The symbols \`a' and \`$\underline{t}$' will represent a low, back, open vowel and voiceless dental plosive respectively, in this paper.

2.The word /halI/ is a non-word which was introduced to the child as the name of the carricature of a worm.

at a comfortable level. In addition 20 words were randomly re-played to the subject as a reliability check. The identification task were played in the form of games so as to avoid fatigue. Only 30 words from the list were presented during one session.

i) **Perception test I (Adult production):-**

The 40 stimulus words spoken by one female adult speaker along with 20 repetition for reliability check was presented to individual subjects in the experimental group.

ii) **Perception test II(self perception):-**

The stimulus words spoken by a velar fronting subject recorded during the production task were played back to the same subject. Through digital editing techniques the words spoken by the experimental group were randomised and any speech other than the stimulus words was eliminated. A further twenty words were repeated as a reliability check. Thus in all each child in the experimental group listened to his own recorded tokens of sixty stimulus words (The recorded /k^halI/ and /$\underline{t}^h$alI/ were the same as those acoustically analysed in experiment I.).

iii) **Perception Test III (Fronted production) :-**

One trained adult in control group II and the children in control group I participated in this test. The trained adult listened to audio tape recordings of 60 (40+20) stimulus words attempted by <u>each</u> of the subjects in the experimental group and identified the words. Thus in all the adult subject listened to all ten velar fronting subjects. Each child in the control group I, listened to an audio tape recording of 60 (40+20) words spoken by <u>one</u> of the subjects to whom they were matched in the experimental group and identified the words.

iv) Perception test IV (Segmented list):-

The 40 stimulus words attempted by the velar fronting subjects were segmented to form the test stimuli for this perception test. The initial aperiodic portion of the consonant was excised from stimulus words /k^{h}ali/ and /t̪^{h}ali/ spoken by the subjects themselves. The decoy words /pali/ and /hali/ were included without segmenting. This formed, therefore, a tape of 40 stimulus words, along with 20 words repeated for reliability, which will be referred to as the `segmented list'. Each subject in the experimental group listened to his\her own "segmented list".

5.2.4 Scoring:-

All correct responses were given a score of one. Furthermore, the word which was confused for the word attempted, was also noted down so that confusion matrices could be made.

5.3 Results:

The mean and standard deviation of percentage correct identification score for the subjects in the experimental group while listening to tape recorded speech stimuli spoken by an adult and for their own tape recorded tokens are given in table 5.1.1. Analysis of the 20 tokens which were repeated indicated that the subjects were 100% reliable for adult speech stimuli and 96% for their own production.

Table 5.1.1:- The mean and standard deviation of percentage correct identification score for subjects with velar fronting while listening to speech stimuli spoken by (i) an adult and (ii) their own production.

Speech Stimuli	Identification score Mean(%)	SD
(i) Adult o/p	99.25	.67
(ii) Self o/p	77.25	1.85

The confusion matrix of the target word vs. the identified word were made for the listeners in the experimental group while listening to their own production, (Table 5.1.2) . The one sample proportion test was applied to group data to ascertain if the subjects were identifying velar and dental initial words and the two decoy words significantly better than chance. The obtained Z value of -8.43 and -1.62 for the velar and dental initial words indicates that the subjects were performing at chance while identi-

Production Output	Perceptual response /khali/	/t̲hali/	/pali/	/hali/	Total
/khali/*	27	58		15	100
/t̲hali/	9	86		5	100
/pali/		1	98	1	100
/hali/	2		1	97	100
Total	38	145	99	118	400

Table1 5.1.2:- The confusion matrix of the word attempted and the word perceptually identified by subjects in the experimental group while listening to their own rendition of the target words.

(* Note that out of 100 attempted /k^{h} alI/ tokens 91 tokens were transcribed by ASs1 as fronted) fying these two words in their own production. In the case of the two decoy words the obtained Z value of -0.23 and -.35 indicates that the subjects were performing significantly above chance at identifying /palI/ and /halI/. On examining the subjects' individual confusion matrix for the target word vs. the identified word, it became evident that subject ESs1, ESs2, and ESs9, perceived all their error sounds as dentals. However, this was not true for the other seven subjects (Table 5.1.3 to 5.1.9 gives the individual confusion matrix for subjects ESs3, ESs4, ESs5, ESs6, ESs7, ESs8, and ESs10 respectively). Since a score of greater than 5 is above chanceat the 0.99 level of significance, experimental group subjects, ESs3, and ESs5 were identifying velars above chance while listening to their own output (chance is 0.25). Both the subjects in the control group I and II, identified all the /k^{h}alI/ targets attempted by subject ESs3, and ESs5 as being fronted.

The mean and standard deviation of percentage correct identification score for the subjects in control group I (children) and II (adult trained) while listening to the tape-recorded speech stimuli output of subjects in the experimental group are given in table 5.1.10. Both the control groups obtained similar scores on this task. Their reliability performance on this perceptual task was 97% and 96% respectively.

Production Target	Perceptual response /khali/	/t̲hali/	/pali/	/hali/	Total
/khali/ *	7	1		2	10
/t̲hali/	2	6		2	10
/pali/		1	9		10
/hali/				10	10
Total	9	8	9	14	40

Table 5.1.3:- The confusion matrix of the word attempted and the word perceptually identified while listening to the subject's own rendition of the target words by subject ESs3 from experimental group.

(* Note that out of 10 attempted /k^halI/ tokens 10 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response /khali/	/thali/	/pali/	/hali/	Total
/khali/ *	3	5		2	10
/thali/	5	5			10
/pali/			10		10
/hali/				10	10
Total	8	10	10	12	40

<u>Table 5.1.4:</u>- The confusion matrix of the word attempted and the word perceptually identified while listening to the subject's own rendition of the target words by subject ESs4 from experimental group.

(* Note that out of 10 attempted /k^h alI/ tokens 10 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response /khali/	/t̲hali/	/pali/	/hali/	Total
/khali/	5	3		2	10
/t̲hali/		9		1	10
/pali/			10		10
/hali/				10	10
Total	5	12	10	13	40

Table 5.1.5:- The confusion matrix of the word attempted and the word perceptually identified while listening to the subject's own rendition of the target words by subject ESs5 from experimental group.

(* Note that out of 10 attempted /k^{h}all/ tokens 10 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response /khali/	/t̲hali/	/pali/	/hali/	Total
/khali/ *	3	6		1	10
/t̲hali/	2	8		1	10
/pali/			10		10
/hali/				10	10
Total	5	14	10	11	40

Table 5.1.6:- The confusion matrix of the word attempted and the word perceptually identified while listening to the subject's own rendition of the target words by subject ESs6 from experimental group.

(* Note that out of 10 attempted /k^halI/ tokens 10 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response /khali/	/t̲hali/	/pali/	/hali/	Total
/khali/ *		4		6	10
/t̲hali/		9		1	10
/pali/			10		10
/hali/				10	10
Total		13	10	17	40

<u>Table 5.1.7:</u>- The confusion matrix of the word attempted and the word perceptually identified while listening to the subject's own rendition of the target words by subject ESs7 from experimental group.

(* Note that out of 10 attempted /k^{h} alI/ tokens 9 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response /khali/	/thali/	/pali/	/hali/	Total
/khali/ *	4	3		3	10
/thali/		9		1	10
/pali/			10		10
/hali/				10	10
Total	4	12	10	14	40

Table 5.1.8:- The confusion matrix of the word attempted and the word perceptually identified while listening to the subject's own rendition of the target words by subject ESs8 from experimental group.

(* Note that out of 10 attempted /k^halI/ tokens 5 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response /khali/	/t̲hali/	/pali/	/hali/	Total
/khali/ *	4	6			10
/t̲hali/		10			10
/pali/			10		10
/hali/	1			9	10
Total	5	16	10	9	40

Table 5.1.9 :- The confusion matrix of the word attempted and the word perceptually identified while listening to the subject's own rendition of the target words by subject ESs10 from experimental group.

* (Note that out of 10 attempted /k^{h}alI/ tokens 9 tokens were transcribed by ASs1 as fronted)

Table 5.1.10:- Percentage correct identification score for subjects in control group I and II while listening to the speech stimuli attempted by the subjects in the experimental group.

Listeners in Control Group	Identification score Mean(%)	SD
I	76.25	1.58
II	76.25	1.96

Confusion matrices for the word output of the experimental group vs. the word identified by the control groups I and II while participating in perception test III are given in Table 5.1.11 and 5.1.12 respectively. It is clear from these tables that as a group both the control groups heard most of the velars as being fronted. From the individual confusion matrix, it became apparent that adult trained listeners and children with no production errors, heard all the velars as being replaced by a dental in the recordings of all subjects except those of ESs2 and ESs8. Individual confusion matrices for adult trained listener for these two subjects are given in Table 5.1.13, and 5.1.14 respectively. From the individual confusion matrix for the child listener in control group I, it was clear that all the velars attempted by experimental group were generally heard as being replaced by a dental in the recordings of all subjects except those of ESs2, ESs7, ESs8, and ESs10 Table 5.1.15, 5.1.16, 5.1.17, and 5.1.18 respectively).

Production Output	Perceptual response				Total
	/khali/	/thali/	/pali/	/hali/	
/khali/*	8	89		3	100
/thali/	2	97	1		100
/pali/			100		100
/hali/				100	100
Total	10	186	101	103	400

Table 5.1.11:- The word attempted and the word perceptually identified by subjects in control group I while listening to the output of subjects in experimental group.

(* Note that out of 100 attempted /k^halI/ tokens 91 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response				Total
	/kʰali/	/k̟ʰali/	/pali/	/hali/	
/kʰali/*	6	89	2	3	100
/k̟ʰali/	1	99			100
/pali/			100		100
/hali/				100	100
Total	7	188	102	103	400

Table 5.1.12:- The word attempted and the word perceptually identified by subjects in control group II while listening to the output of subjects in experimental group.

* (Note that out of 100 attempted /kʰalI/ tokens 81 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response /khali/	/ṭhali/	/pali/	/hali/	Total
/khali/*	2	6		2	10
/ṭhali/	2	7	1		10
/pali/			10		10
/hali/				10	10
Total	4	13	11	12	40

Table 5.1.13:- The word attempted and the word perceptually identified by subjects in control group II while listening to the output of subject ES2.

(* Note that out of 10 attempted $/k^{h}alI/$ tokens 9 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response /khali/	/ţhali/	/pali/	/hali/	Total
/khali/*	6	3		1	10
/ţhali/		10			10
/pali/			10		10
/hali/				10	10
Total	6	13	10	11	40

Table 5.1.14:- The word attempted and the word perceptually identified by subjects in control group I while listening to the output of subject ES8.

(* Note that out of 10 attempted /k^{h} alI/ tokens 5 tokens were transcribed by ASs1 as fronted)

Production Output	Perceptual response /khali/	/t̲hali/	/pali/	/hali/	Total
/khali/*	1	9			10
/t̲hali/	1	9			10
/pali/			10		10.
/hali/				10	10
Total	2	18	10	10	40

Table 5.1.15:- The word attempted by velar fronting subject ESs2 and the word perceptually identified by subject in control group I. (* Note that out of 10 attempted /k^halI/ tokens 9 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response /khali/	/t̲hali/	/pali/	/hali/	Total
/khali/ *		9		1	10
/t̲hali/		10			10
/pali/			10		10
/hali/				10	10
Total		19	10	11	40

Table 5.1.16:- The word attempted by velar fronting subject ESs7 and the word perceptually identified by subject in control group I.

(* Note that out of 10 attempted /k^{h}alI/ tokens 9 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response /khali/	/t̲hali/	/pali/	/hali/	Total
/khali/ *	5	4		1	10
/t̲hali/		10			10
/pali/			10		10
/hali/				10	10
Total	5	14	10	11	40

<u>Table 5.1.17:-</u> The word attempted by velar fronting subject ESs8 and the word perceptually identified by subject in control group I.

(* Note that out of 10 attempted /k^halI/ tokens 5 tokens were transcribed by ASs1 as fronted)

Production Target	Perceptual response /khali/	/t̲hali/	/pali/	/hali/	Total
/khali/ *		7	2	1	10
/t̲hali/		10			10
/pali/			10		10
/hali/				10	10
Total		17	12	11	40

<u>Table 5.1.18:-</u> The word attempted by velar fronting subject ESs10 and the word perceptually identified by subject in control group I.

(* Note that out of 10 attempted /k^halI/ tokens 9 tokens were transcribed by ASs1 as fronted)

5.4 Discussion:

The various perception tests primarily attempted to ascertain whether subjects with velar errors perceived $[k^h] \sim [\underline{t}^h]$ in adult production and in their own renditions. All the subjects with isolated difficulty in velar production, had no difficulty in identifying $[k^h] \sim [\underline{t}^h]$ contrasts in adult production. The results rejects the first hypothesis. This is in agreement with other studies applying not only to $/k^h/\sim/\underline{t}^h/$, but also other classes of sound and with clinical observations (Locke, 1980a,b,c).

The overall identification score of 77.3% reported in table 5.1.1 for these subjects while listening to their own production attempts at $[k^h] \sim [\underline{t}^h]$ contrasts, appear to be comparable to the correct identification scores obtained by adult trained listeners (76.3%) and children with no production errors (76.3%) while listening to the same audio tape recordings of the minimal pairs (table 5.1.10). The difference between the two groups was observed in the SD alone. Thus overall group scores appear to indicate that the second null hypothesis is true. However, the confusion matrix appears to be a better indicator of the person's perceptual capabilities and tendss to reject null hypotheis two. From table 5.1.2, 5.1.11 and 5.1.12 it is clear that the three groups differed in their perception of the output of subjects in experimental group for target words $/k^halI/$ and $/\underline{t}^halI/$. Most of the positive identifications for the control groups were made by subjects ESs2 and ESs8, who had produced correct $/k^halI/$, in agreement with narrow transcription (Table 4.2.A in page no.128).

The subjects with velar fronting identified more of their output for the target word $/k^halI/$ as $[k^halI]$ than the subjects in both the control groups (Table 5.1.2, 5.1.11, 5.1.12). Subjects ESs3 and ESs5 were able to identify their $/k^halI/$s well above chance indicating that there may be critical acoustic differences between their velar error and dental sounds which may be important to them perceptually. On examining the acoustic differences in $/k^halI/$ and $/\underline{t}^halI/$ for these two subjects it was observed that ESs3 maintained significantly longer durations for vowel [a], VOT, aspiration and word in $/k^halI/$ than in $/\underline{t}^halI/$ (Table 4.2.40 in page no.243). However, such was not the case for output from subject ESs5 who maintained significant acoustic difference for only two of the acoustic parameters. Surprisingly, subject ESs8 who maintained significant difference in five acoustic parameters, failed to identify her correctly articulated $/k^halI/$. The perceptual response of subjects ESs7 and ESs8 may be interpreted as demonstrating evidence that these two subjects were perceiving certain critical acoustic differences in their $/k^halI/$ attempts. From table 5.1.7. and 5.1.8 it may be observed that 6 of the attempted $/k^halI/$ were identified as /halI/ by ESs7 and that ESs8 appears to have greater difficulty in deciding whether an attempted /k^halI/ had a initial velar stop or a glottal fricative rather than from a dental initial word. So the findings from perception test I (adult production), II (self perception), and III (fronted production), may be interpreted as evidence for auditory sensitivity of velar fronting subjects to critical acoustic features or combination of features in their output.

The auditory perceptual distinction exhibited by experimental group appears to become clear from the confusion matrix, rather than from overall `discrimination scores'. An interesting feature which emerges from examining the confusion matirices is the tendency for the experimental group to confuse their fronted production as a glottal fricative. Except for subjects ESs1, ESs2, and ESs9, the subjects who fronted their velars appear to confuse perceptually their own renditions of /k^halI/ and /$\underline{t}^h$alI/ with the other more open member of the minimal set, namely /halI/. From table 5.1.3 to 5.1.9, it is clear that these subjects rarely confused these words with the bilabial minimal pair /palI/. Furthermore, /halI/ is rarely confused with any other word of the set. From these results of perception test I, II and III, it may be concluded that there may be a sub-group of subjects with isolated difficulty with velars who have a different auditory sensitivity to the [k^h]~[$\underline{t}^h$] contrast than that exhibited by persons who have mastered this contrast in their production.

The findings that subject ESs3 could actually correctly identify seven out of ten of their output while targeting /k^halI/ further strengthens this conclusion and also suggests that these subjects processed the various acoustic cues in their production differently than adults or children who have mastered this contrast in their own production. The findings questions the contention of various researchers that in all subjects with output errors, the individual perceives the phoneme correctly but due to insufficient knowledge of phonological rules or processes alone, produces a surface form which is erroneous (Stampe, 1973; Braine, 1976; Dongar & Stampe, 1979; Ingram, 1971; Menn, 1978; Smith, 1973). The above contention may be more applicable to those output errors which are due to normal developmental processes rather than to those which occur as a result of disordered speech processing.

The discrepancy in the experimental group subjects' perception of adult recorded tokens and their own recorded tokens may be interpreted as reflecting the subjects' dependency on extreme `forms/values' for auditory labeling. In other words the experimental group has not yet developed "categorical perception" for their error production. Although the perception tests were not specifically designed to ascertain the subjects categorical perception, the inclusion of /halI/ appears to provide further evidence of auditory dysfunction. The target /halI/ tokens were rarely confused with /$\underline{t}^{h}$alI/ or /k^{h}alI/. However, the reverse was often true. If the subject was dependent on durational features of aspiration, VOT, and vowel features, the child would present this confusion. Furthermore, absence of transient may have made it easier to separate the glottal fricative from the plosives.

Transients which indicate sudden release are associated with plosives. Absence of a transient while producing /halI/ would assist the velar fronting subject in accurately identifying all targeted /halI/s correctly. On the other hand, acoustic analysis indicated that transient durations were significantly longer for subjects with velar fronting. A larger transient duration may result in the perception of a slow release as in fricatives. This may have resulted in the confusion of attempted /k^{h}alI/ as /halI/. However, this does not explain why attempted /$\underline{t}^{h}$alI/ which also had longer transient durations were rarely confused with /halI/. From table 5.1.3, 5.1.4, 5.1.5, 5.1.7, and 5.1.8, it may be observed that subjects ESs3, ESs4, ESs5, ESs7, and ESs8, mainly contributed to the confusion of attempted /k^{h}alI/ with /halI/. From Table 4.2.10 (page no.243), it may be noted that subjects ESs3, ESs4, ESs7, and ESs8, also maintained significant differences in more than two acoustic parameters for attempted /k^{h}alI/ and /$\underline{t}^{h}$alI/. Perhaps the acoustic differences as a whole lead to the perception of /halI/ in the attempted /k^{h}alI/ tokens.

The analysis of data in the present study did not directly attempt to correlate the acoustic features with the subjects perception of contrasts in his own production. Initially, however, an experiment was designed to ascertain whether the performance of the subject while listening to their own production with the 'burst' deleted would be effected (perception task IV). The main aim of perception test IV, was to ascertain whether subjects with velar fronting depended more on burst or transient information. Since this experiment was conducted prior to undertaking acoustic analysis of data, the experimenter did not realise that by deleting the initial aperiodic portion, the `entire' transition would also be deleted. It may be noted that both experimental and control group I subjects tended to perform at chance while identifying /$k^h$alI/, /$\underline{t}^h$alI/, /palI/ and /halI/ while listening to the `segmented list'. Hence the results of this experiment had to be dropped from the study.

Evidence from self-perception test and acoustic analysis application in experiment I, indicates that some subjects with velar fronting may be auditorily sensitive to durational difference in their output for /k^halI/ and /$\underline{t}^h$alI/. Hawkins (1986a,b) reported that 6 of her "normal" adult subject set of demonstrated performance for a different set of acoustic parameters for making confident judgement of `velars' in velar-labial and velar-dental synthesized continuum. These subjects appeared to hear differences which they were unwilling to classify as velars. One wonders why some of the children in the present study depend on sensitivity to durational variants rather than spectral features and how acquisition of "normal" or adult categorical perceptual skills is disrupted. Are these children presenting a disorder or a delay? Whether in the children this reflects the response of a disrupted auditory system to the requirement of categorical perception in speech communication, or to the remnant of a developmentally earlier skill is open to discussion and requires further investigation.

Clinical evidence indicates that intermittent hearing loss effects phonological development (Haggard, Birkin & Pringle, 1993). The exact nature of this etiological factor has not been addressed. It would be interesting to ascertain the speech perceptual capabilities of children with intermittent hearing loss in their period of phonological development, and ascertain if a later phonological disorder can be predicted on this basis. That is, does intermittent hearing loss disrupt the development of categorical perceptual skills and hence result in output disorder? Having a disordered auditory perceptual system may force the developing child to continue to depend upon developmentally earlier features to maintain contrasts in his output, denying him the opportunity to learn the adult perceptual features for the contrast.

Although research findings consistently point to the presence of a sub-group of phonologically disordered subjects who have different auditory perceptual skills for the output error, its impact on clinical differential diagnosis and therapy has been minimal. This may be due to the lack of clinically viable tools for identification. Time consuming acoustic analysis procedures, lack of skills in using acoustic analysis techniques, the non-availability of test for categorical perception, may all contribute to lack of close attention to the relationship between perception and production as a regular part of assessment protocol for children with disorders of speech output. It would seem that a natural progression from the results of this and other recent studies would be the development of self perception tests with confusion matrices, which could be readily applied as routine, and which might then be capable of throwing further light on this difficult area.

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6 Chapter VI: SUMMARY AND CONCLUSIONS

Nine children (age range of 5;2 to 9 years) and one 20 year old adult, with velar fronting formed the experimental group. Ten subjects matched in age and sex to the experimental group but with no production errors were included in control group I. All subjects in the experimental group fronted velars in all positions and had not yet approached anyone for professional help. The 20 year old female with velar fronting was also included in this group but she had attended some sessions of therapy. All subjects spoke either Hindi or Marati at home and knew one of these languages as a second language. They participated in a picture naming task. The speech stimuli consisted of the words /k^halI/, /$\underline{t}^h$alI/, /palI/, and /halI/. except for the words /halI/, all the words were meaningful in both languages. The production attempts were audio tape recorded for perceptual and acoustic analysis. These recorded tokens were also employed in a test of perception.

The perceptual and acoustic analysis mainly attempted to answer the following questions

1) Do children with velar fronting consistently substitute a dental plosive for the target velar sound?

2) Do children who front velars in their production maintain acoustic differences between their velar error productions and replacing lingual stop consonant?

3) Are there acoustic differences in word initial velar and lingual stop contrasts attempted by children fronting their velars, and children with no production errors?

The tests of perception mainly attempted to ascertain answers to the following questions:-

1) Do subjects with velar fronting auditorily contrast velar and dental initial words spoken by adults?

2) Do subjects with velar fronting perceive all their attempted velar initial words as dental initial words?

3) Is there a significant difference between the identification score obtained by subjects with velar fronting and subjects with no production error, while listening to velar and dental initial worse attempted by velar fronting subjects?

Perceptual analysis of /k^{h}alI/ and /ṯ^{h}alI/ tokens from velar fronting subjects indicated that:-

1) All subjects with velar fronting do not always replace the [k^h] in /k^{h}alI/ with [ṯ^h]. Besides replacing with /ṯ^h/, the subjects also substituted sounds such as [ṯ], palatalized [ṯ], [θ], [ʈ^h], [h], [ḏ^h], labialized [ṯ^h], and [ṯ$^h_ɣ$].

2) Some velar fronting subjects do not always produce the replacing sound accurately, that is the dental aspirated sound in /ṯ^{h}alI/ was often substituted by the following sounds, [ṯ],[ʈ^h],[ṯ^h_v], and [ʈ].

3) The transcription skills of an adult trained listener may be dependent on the first language of the listener and the experience of the listener.

Acoustic analysis was done for nine subjects in the experimental group and five subjects randomly selected from control group I. Initially the Blumstein and Steven's template matching approach to identifying place of production was applied to the audio taped tokens of /k^{h}alI/ and /t̪^{h}alI/ from control group I. The results indicated that this acoustic analysis technique was not useful in differentiating velars and dentals produced by children. Further acoustic analysis included detailed measurement of both spectral and durational parameters. The results indicated that as a group the five subjects in control group I maintained statistically significant difference in formant two measures in transient, post-transient, aspiration, vowel [a] segments, VOT, and duration of transient. It was concluded that in children:-

1) velars have lower formant two related measures than in dentals.

2) velars have longer transient duration than dentals.

3) vowel [a] following a dental plosive has a higher formant two frequency than when it follows a velar.

4) formant two related measures in velars are not always higher in the transient region as compared to formant two of the following vowel [a] in some children.

5) both group statistical analysis and single case ap-

proaches to studying acoustic differences in production are important while analyzing child data.

Acoustic analysis of the recorded tokens of /k^halI/ and /$\underline{t}^h$alI/ attempted by experimental group indicated that:-
1) the duration of the attempted word /k^halI/ and the duration of the vowel [a] was longer than those measured in the word /$\underline{t}^h$alI/ for most subjects.
2) the F0 of velar fronting subjects is higher than those with no output error in the same age range.
3) some subjects with velar fronting maintain significant acoustic difference for attempted /k^halI/ and /$\underline{t}^h$alI/ in more than two acoustic parameters.
4) group statistical analysis do not indicate the nature of velar fronting as there is considerable variation in the acoustic parameters in which significant differences were observed for each subject.
The experimental and control groups also participated in perception tests to ascertain whether the observed acoustic differences were "critical" to the experimental group. All the subjects identified the audio taped stimulus words spoken by an adult speaker and by the velar fronting subjects, via a four alternative forced choice picture identification task (4IAX). The results indicated that:-
1) subjects with isolated difficulty in velar production, had no difficulty in identifying [k^h]~[$\underline{t}^h$] in adult production.
2) the confusion matrix appears to be a better indicator

of the person's perceptual capabilities. It differed in their perception of their own audio taped output, as compared to the performance of children and adult listeners with no output errors who also identified the same audio taped tokens via the 4IAX.

3) some velar fronting subjects do not always confuse their attempted initial velar stop word as a dental stop. There appears to be a trend to confuse attempted velars as glottal fricatives.

4) the perceptual responses of some subjects indicated that they were perceiving certain "critical" acoustic differences in their /k^halI/ and /$\underline{t}^h$alI/ attempts.

<u>Suggestions for future research:-</u>

The results of the current study, and the thinking to which they lead, indicate a number of questions which might form the basis for future research, namely

1) Is it true that greater the number and degree of differences in acoustic parameters for attempted velar sound the greater the chance that it will not be classified as a dental sound?

2) Are durational differences alone sufficient for velar fronting children to classifying a fronted velar initial word as a velar word?

3) Do subjects with phonological errors have higher fundamental frequency and formant frequency than children in the same age and sex with no output errors?

4) Do children with velar fronting classify adult tokens of substituted phoneme differing in segmental duration such as duration of transient, aspiration, following vowel, and VOT, as velar consonants.

5) Do subjects with a history of intermittent hearing loss prior to the acquisition of speech sounds also demonstrate abnormal categorical perception?

6) Is training in categorical perception alone sufficient for facilitating acquisition of the error sound?

7) Are confusion matrixes sensitive to identifying subjects with phonological disorders who have categorical perceptual difficulty?

8) Will palatographic findings support acoustic findings indicating differences in the velar targeted word and the substituted word?

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7 Chapter VII: REFERENCES AND BIBLIOGRAPHY

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8 APPENDIX I: Pilot Study

Two pilot studies were conducted to ascertain whether children with velar misarticulation acoustically mark their velar/alveolar contrasts to which they are auditorily sensitive. The pilot studies were found to be necessary to resolve certain methodological issues regarding acoustic analysis of alveolar and velar sounds and synthetic alveolar/velar stimuli generation. In the pilot studies only natural speech stimuli were employed in the perception task because generating synthetic alveolar/velar speech stimuli posed a problem because of the controversy regarding the primary acoustic cue to place of articulation in stop consonants. Furthermore, a major problem in spectrographic analysis of children's speech is the poor resolution of formants. The high fundamental frequency of voice in children is the main source of this problem (Huggins,1980). On examining the two different acoustic cues to place information in stop consonants- spectral shape sampled at onset of stop consonants and the formant transitions, it was felt that the former would be easier to implement on child speech than measuring formant transitions. Also according to Blumstein and Stevens (1978) the shape of the stop onset spectrum of initial stops show invariant properties independent of the adjacent vowel or the voicing characteristics of the consonant. Hence a large number of velar/alveolar minimal pair contrasts could be included as stimulus material. The pilot studies attempted to ascertain whether velar misarticulating children

(1) maintain allophonic acoustic differences between their velar errors and alveolar sounds?

(2) are auditorily sensitive to allophonic differences in their velar errors and alveolar sounds?

Furthermore, the pilot studies attempted to ascertain whether the Blumstein-Stevens template is adequate for differentiating alveolars and velar onset spectrum derived with the Kay elemetrics sonograph workstation?

8.1 Methodology

8.1.1 Experiment-I

8.1.2 Subjects:-

Speech-language clinicians were requested to select children whose speech patterns included fronting of velars. A total of nine children were referred, 5 of whom (4 males and 1 female) were found to meet the criterion of isolated misarticulation of velars. Their age ranged between 4.5 years to 6 years. None of the children demonstrated cognitive and /or hearing deficits. The subjects will be referred to as SB, CD, SM, LG and DH henceforth.

8.1.3 <u>Speech stimuli</u>:-

Ten familiar minimal word pairs containing velar and alveolar stops including voiced and voiceless cognates in initial and final word position were selected.

\`down-gown'	\`net-neck'
\`done-gun'	\`bat-back'
\`toffee-coffee'	\`sit-sick'
\`tea-key'	\`bed-beg'
\`tap-cap'	\`mud-mug'

An attempt was made to select an equal number of front and back vowels. These words were randomised to form two lists of 20 words. Line drawing pictures were used to elicit responses.

8.1.4 **<u>Production task</u>:-**

Whenever possible the words were elicited spontaneously using a picture naming task. Occasionally "repeat-after-me" was employed to record a word in isolation. Recordings were made on a high quality Sony monophonic audio professional cassette player, with the microphone kept eight inches in front of the mouth. All recordings were made in the clinic/school in quiet room conditions.

8.1.5 **<u>Perception task</u>:-**

A two alternative forced choice picture identification task was employed in both perception tasks. The stimulus words were randomly presented through headphones at a comfortable level. The identification task was played in the form of games so as to avoid fatigue . All five children participated in two perception tasks.

(i) Perception task I:- In this task the auditory stimuli consisted of 20 adult production of the stimulus words in random order.

(ii) Perception tasks II:- In this task the auditory stimuli consisted of the Experimental group's own production of the stimulus words. The words spoken by each subject during the production task was randomly transferred to another tape to form the stimulus list for this task.

8.1.6 **Acoustic analysis of stop consonant:-**

Both adult and child production were analysed spectrographically. Auditory analysis indicated that most children realised final stops with release bursts. The Kay Elemetrics D.S.P Sonograph model 5500 (workstation) was employed for deriving stop consonant onset/offset spectra. The Kay workstation has the option "power between cursors" which was used for deriving the onset/offset Fast Fourier Transform (FFT) spectra as at the time of analysis LPC averaging facility was not available to the researcher. This option provides two cursors which can be moved to a selected point along the time axis for deriving a time integrated frequency vs. intensity spectrum. As far as possible 26 ms of the onset/offset was averaged as this is the recommended duration employed by Stevens and Blumstein (1978) while deriving the LPC spectra for their template matching procedure. Wherever the VOT was more than 26 ms, the initial or final 26ms was included. Care was taken not to include the steady state portion of the following vowels. The Hi-shape function was used giving a Hi-frequency pre-emphasis of 6dB/octave above 1kHz. As auditorily most of the productions sounded like an alveolar plosive, the Stevens-Blumstein template for alveolar stops was employed for accepting or rejecting a fit.

8.2 Results and Discussion

Generally it was expected that velar misarticulating children would have no difficulty identifying stimulus words spoken by adult speakers. However four of the subjects CD, SM, LG and DH performed at chance level (50%). Their average total correct identification was 13/20. This finding was surprising as the District Speech-language pathologist's observations during informal auditory training games was that these children had no difficulty in identifying correct velars in adult production. Perhaps the factor that the subjects were from a lower socio-economic section may have interfered in their ability to attend to tape-recorded stimuli (two of the subjects said that they had never "listened on a walkman" before). The subject SB scored 19/20 correct identifications on the same task. Hence only SB was retained for participation in further tasks.

Subject SB scored a high correct identification score of 16/20 on perception task II. Ten words were randomly repeated as a reliability check on which SB obtained 8/10 which indicated that the subject had understood the task and was consistent in his responses. From an auditory analysis of the production data it was found that SB was misarticulating mainly word initial velars. Hence it was felt that the high score was because of the limited error sounds in the rendition of stimulus words. In the self-perception task an error analysis was conducted with the following findings:

(1)	Total number of errors	4/20
(2)	Number of correct identification when the velar sound was misarticulated.	3/5
(3)	Number of incorrect identification when the velar sound was correctly produced.	1/5
(4)	Number of incorrect identification when the alveolar stop was produced correctly.	1/10

From this analysis it becomes apparent that SB did not identify all his velar errors and alveolars as alveolars. His error score of 2/5 indicates that he was performing at chance in identifying a production as a clear /k/ or /t/. Trained listeners identified all the error sounds as /t/. The results on self perception appears to be in agreement with earlier studies that some misarticulating children appear to be using different identification strategies than adult listeners (Hoffman, 1983).

Template Diffuse-rising suggested for alveolars by Stevens and Blumstein (1978) was applied to the onset/offset spectrums (frequency vs. intensity) derived with the Kay workstation for words spoken by SB and the adult female speaker, it was found that the template was not effective in differentiating the alveolar stops of both the child and adult speakers. On inspecting the onset spectrum it was observed that for the voiced cognates, strong low frequency peaks in the spectrum interfered with the categorisation of the onset/offset spectrum by the diffuse-rising template into /t/ and /k/. Separate analysis of voiced /voiceless stops was not possible because of the limited number of tokens. It was difficult to ascertain whether the observed differences were due to within speaker variability for the specific stimuli or whether the acoustic difference was relevant to the subject for signalling meaning difference. Considering the above observations it was felt prudent to stop data collection and select a narrower set of minimal words pairs with more repetitions.

8.2.1 **Experiment: II**

Based on the observations made in Experiment I, three major changes were introduced in the methodology. Only initial voiceless alveolar and velar plosives. The total number of stimulus word in each list was increased to forty. Finally the score obtainable by chance was reduced by using an eight alternative forced choice picture identification task (8AIX) paradigm instead of a two alternative forced choice picture identification task (AX) paradigm used in Experiment I.

8.2.2 **Speech stimuli:-**

Four initial voiceless velar and alveolar minimal word pairs were selected. All the words had the same vowel following the initial consonants. The words tot, cot, toffee, coffee, top, cop, tock and cock were selected and randomised in such a manner that there were five occurrences of each word (8X5). Thus there were two separate randomised lists of 40 stimulus words each for both production and perception tasks. Line drawings of the words were again used to elicit responses. Ten words were randomly repeated to check reliability in the perception tasks.

8.2.3 Experimental group:-

Five male children (in the age range 4.5-9 years) with isolated difficulty in the production of velar stops were selected for the study. None of the children demonstrated cognitive, language and/or hearing deficits. They will be referred hence fourth as A.M., S.B., M.M., D.I. and A.G. A.G. was unable to cooperate fully with the perception task was distractible and was therefore excluded from the group. The remaining four subjects took part fully. One of the subjects in this group (A.M.) was producing alveolar ejectives and occasionally glottal stops for velar plosives in his speech. However A.M. was not dropped from the study. Only S.B. had participated in the experiment I.

8.2.4 Control groups:-

All subjects (in the control group) had normal speech and hearing skills .

Control group I:-

Seven children in the age range 4.5-9 years (4 girls and 3 boys) were assigned to the first control group, to participate in the production task.

Control groups II:-

Eight trained adult listeners were assigned to this group to participate in the perception task III.

8.2.5 **Production task:**-

Subjects in the experimental group and control group-I participated in this task. Each child was shown the picture cards of the stimulus word, one at a time and asked to name the pictures. Recording conditions were the same as for Experiment I.

8.2.6 **Perception task:**-

A total of three perception tasks were conducted. An eight alternative forced choice picture identification task (8AIX) was employed in all the perception tasks. A list of 40 stimulus words was presented to the listener one at a time through headphones at comfortable levels. The listeners were asked to point to the picture which corresponded to the auditorily presented word. The task was played in the form of a game in case of children. Only 20 words were presented during one session to avoid fatigue. The various perception tasks were as follows:-

Perception task I:-

Forty stimulus words spoken by an adult female speaker were presented randomly to the experimental group in this task.

Perception task II:-

Children in the experimental group listened to 40 words spoken by themselves in the earlier session.

Perception task III:-

Adults in control group II were presented 40 words spoken by all four children from the experimental group.

8.2.7 **Acoustic Analysis:-**

All the words spoken by the experimental group and control group-I were analysed as per the procedure specified in experiment-I. In addition, the VOT of initial consonants were measured from spectrographs in accordance with the procedure suggested by Lisker and Abramson (1964) and the frequency of the highest peak after 4 kHz was also measured (Hewlett, 1988).

8.3 **Results**

All four subjects in the experimental group performed extremely accurately in identifying stimulus words spoken by the normal adult. They obtained a mean correct score of 38.5/40 with a Range of 3. The experimental group obtained considerably lower identification scores while listening to their own rendition of the stimulus words as compared to their score while listening to adult rendition. Confusion matrix of the target word vs. the identified word were made for the listeners in the experimental group while listening to their own production and for the adult listeners (Table: A1.1 and A1.2). From the confusion matrix for velar misarticulating children in the self-perception task (Table: A1.1), it becomes apparent that the confusions were not always within a minimal pair, for example cot-tot, but also across minimal pairs, for example cot-top or tock-cop.

Hence two methods of score analysis was possible. Firstly the overall correct identification of stimulus word (table A1.3: sl.no. 1) and for velar and alveolar initial words separately (Table A1.3: sl.no.2 to 5). Secondly a subject may make an incorrect identification of the word but the initial consonant may be the same as the stimulus word, for example for stimulus word cop, the subject selects cock. Such a child was considered to have correctly identified the initial consonant but unable to identify the final consonant. Hence a separate analysis of such instances were made (Table A1.3: sl.no.6,7,8). Finally in an attempt to observe whether the subjects were influenced by the presence of final alveolar and velar consonants in the stimulus word, separate identification scores were calculated for correct identification of initial consonants when final consonant was alveolar or velar sound (Table A1.3: sl.no.9,10). Table-A1.3 presents the identification scores for various categories of stimulus words for the four subjects in the experimental group while listening to their own productions. By chance alone the total correct identification was 5/40, that is0.125. The one sample t-test was applied to the overall correct scores (X=15/40, SD=4.42). The t-value of 3.92 was found to be well above

Table A1.1:- The confusion matrix for the identification of self-produced stimulus words for all children in the experimental group.

Stimulus word	Identification response: cot	tot	coffee	toffee	cop	top	cock	tock
cot	11	7	-	-	-	-	-	2
tot	7	7	-	-	-	-	1	5
coffee	-	-	10	10	-	-	-	-
toffee	-	-	10	10	-	-	-	-
cop	1	2	-	-	4	10	-	3
top	1	2	-	-	6	10	1	-
cock	4	2	-	-	2	3	3	6
tock	6	2	-	-		4	3	5

Table A1.2:- The confusion matrix for the mean identification scores of trained listeners while listening to the renditions of stimulus words by children with velar fronting.

Stimulus word	Identification response: cot	tot	coffee	toffee	cop	top	cock	tock
cot	3.25	9.8	-	-	-	-	-	7.0
tot	5	8.5	-	-	-	-	-	6.5
coffee	-	-	2.0	13.0	-	-	-	-
toffee	-	-	3.0	17.0	-	-	-	-
cop	-	3.0	-	-	3.0	14	-	-
top	1.0	3.0	1.0	-	4.0	10.0	1.0	-
cock	3.5	-	1.25	-	2.3	-	1.5	11.5
tock	-	5.0	-	-	-	5.0	-	13.0

Table A1.3:-Patterns of stimulus word identification for the four subject the experimental group while listening to their own production.

Sl. No.	Scores Type \ Subjects	S.B.	A.M.	D.I.	M.M.	Mean
1	Total correct identification of stimulus words.	15/40	22/40	13/40	10/40	15/40
2	Correct identification of /t/ initial words.	6/20	12/20	8/20	6/20	8/20
3	Correct identification of /k/ initial words.	9/20	10/20	5/20	4/20	7/20
4	Identification of /k/ initial words as /t/initial words.	11/20	9/20	10/20	15/20/20	11.25/20
5	Identification of /t/ initial words as /k/ initial words.	11/20	5/20	12/20	7/20	8.75/20
6	Correct Identification of /t/ initial consonants.	9/20	14/20	8/20	13/20	11/20
7	Correct Identification of /k/initial consonants.	16/20	11/20	12/20	5/20	11/20
8	Correct identification of all initial consonants.	25/40	25/40	20/40	18/40	22/40
9	Correct identification of initial consonants when final consonant was alveolar	7/10	8/10	5/10	3/10	5.75/10
10	Correct identification of initial consonant when final consonant was velar	5/10	3/10	4/10	7/10	4.75/10

chance at the 0.025 level of significance but below .01 level of significance.

The identification scores obtained by adult trained listeners while listening to stimulus words spoken by the Experimental group was analysed. Table A1.4, presents the identification scores obtained by adult listeners for various categories of words. The one sample t-test was applied to the overall correct identification score ($X=12.85$, $SD=1.74$). The obtained t of 7.76 was observed to be well above chance at the .01 level of significance. Although the trained adult listeners obtained lower mean scores than the experimental group, the smaller SD increased the significance of the difference.

The Stevens-Blumstein template for alveolars, that is. diffuse-rising was used to differentiate alveolar/velar onset spectrum for the stimulus words spoken by normal children in the control group I. The template accepted 75% of the Alveolars and rejected only 35% of the velars. Hence the template suggested by Hewlett (1988) was applied to the onset spectrum of stimulus words spoken by the normal children to ascertain its effectiveness in differentiating alveolars from velars. In accordance with Hewlett's(1988) suggestions, that is, "The upper-frequency end (arrow) is placed upon the highest spectral peak above 4kHz, while the base line of the template is held parallel with the x-axis of the spectrum. For /t/ no peak should

Table A1.4:- Mean identification scores of trained listeners on the identification task while listening to the stimulus words spoken by each subject in the experimental group.

Sl. No.	Score Type \ Subject	S.B.	A.M.	D.I.	M.M.	Mean
1	Total correct identification of stimulus word.	12.5/40	15.25/40	13.25/40	10.40/40	12.9/40
2	Correct identification of /t/ initial words.	12.25/20	13.5/20	12.5/20	10.25/20	12.1/20
3	Correct identification of /k/ initial words.	0.25/20	8.5/20	0.75/20	0.25/20	2.4/20
4	Identification of /k/ initial word as /t/ initial words.	19.25/20	9.0/20	17.25/20	17.75/20	15.8/20
5	Identification of /t/ initial word as /k/ initial words.	1.5/20	9.5/20	0.5/20	1.75/20	03.3/20
6	Correct Identification of/t/ initial consonants	18.5/20	10.75/20	19.75/20	18.00/20	17.00/20
7	Correct identification of initial /k/ consonants	00.75/20	11.00/20	2.75/20	2.25/20	04.2/20
8	Correct identification of all initial consonants.	19.25/40	21.75/40	22.50/40	20.25/40	21.6/40

protrude above the line, whereas for /k/ some part of the spectrum should do so."(page. 35). Some modifications had to be made so as to increase the template's effectiveness in differentiating velars and alveolars produced by normal children. The modifications made to the Hewlett template /k/ in the present study were:-

(1) There should be a peak which protrudes above the template at frequencies between 0.5kHz to 2kHz
(2) The peak between 0.5-2k.Hz should be higher than the highest spectral peak above 4kHz.
(3) The low frequency end of the peak should start with a rising slope. If it starts with a downward slope then its starting point should not be higher than the peak between 0.5-2kHz.

Using these modifications it was found that the Hewlett template was able to correctly differentiate between /k/ and /t/ onset spectrum derived for stimulus words produced by children in the control group, with 80% correct acceptance of /t/ and 95% correct rejection of /k/ phonemes (Chance was equal to 50%). The same guidelines were applied for differentiating the onset burst spectrum of the initial consonants produced by the Experimental group. Table A1.5 gives the results of the analysis.

An attempt was also made to differentiate the target contrasts /k/ and /t/ consonants produced by children in the experimental group, in-terms of highest frequency peak beyond 4kHz in the onset spectrum and VOT. On visual inspection, no specific pattern emerged. The mean highest frequency peak beyond 4kHz was observed to be 4129 Hz (SD =857) for velars and 5289 Hz (SD= 1120) for alveolars in /k/~/t/ words produced by children with no production errors. The mean and SD of highest frequency peak beyond 4kHz in the onset spectrum of each initial velar and alveolar minimal pairs attempted by each child with velar fronting is given in Table A1.6. The mean and SD of highest frequency peak beyond 4kHz in the onset spectrum for their attempts at production of velar and alveolar target words are given in Table A1.7. The means for this measure are displayed in the graph in Figure A1.1. The results of completely randomised ANOVA for the difference between the highest frequency peak beyond 4kHz for the two sound type is given in Table A1.10. The obtained F-ratio indicates that there was significant difference in the mean highest frequency peak beyond 4kHz beyond the .05 level of significance. From graph in figure A1.1 it is obvious that S.B. did not maintain significant difference in the /k/~/t/ minimal words. However A.M. maintained a significantly large difference with higher mean for attempted velars than for alveolars ($F(1,38)=19.7$ $p<.0001$).

The third acoustic measure made in this study was VOT. The children with no production error obtained mean VOT of .122 sec.(SD=37.8) for their velar production the experimental group, in-terms of highest frequency peak beyond 4kHz in the onset spectrum and VOT. On visual inspection, no specific pattern emerged. The mean highest frequency peak beyond 4kHz was observed to be 4129 Hz (SD =857) for velars and 5289 Hz (SD= 1120) for alveolars in /k/~/t/ words produced by children with no production errors. The mean and SD of highest frequency peak beyond 4kHz in the onset spectrum of each initial velar and alveolar minimal pairs attempted by each child with velar fronting is given in Table A1.6. The mean and SD of highest frequency peak beyond 4kHz in the onset spectrum for their attempts at production of velar and alveolar target words are given in Table A1.7. The means for this measure are displayed in the graph in Figure A1.1. The results of completely randomised ANOVA for the difference between the highest frequency peak beyond 4kHz for the two sound type is given in Table A1.9. The obtained F-ratio indicates that there was significant difference in the mean highest frequency peak beyond 4kHz beyond the .05 level of significance. From graph in figure A1.1 it is obvious that S.B. did not maintain significant difference in the /k/~/t/ minimal words. However A.M. maintained a significantly large difference with higher mean for attempted velars than for alveolars ($F(1,38)=19.7$ $p<.0001$).

The third acoustic measure made in this study was VOT. The children with no production error obtained mean VOT of .122 sec.(SD=37.8) for their velar production

Table-A1.5:- The number of onset spectra of initial /t/&/k/ consonant accepted/rejected by the template for each of the subjects in the Expt. group.

Initial intended consonant	Acceptance/ rejection of template	No. of onset spectra S.B.	A.M.	D.I.	M.M.	Mean
/t/	Accepted by /t/ template	0/20	9/20	6/20	19/20	8.5/20
/k/	Accepted by /k/ template	20/20	14/20	16/20	10/20	15/20

Table-A1.6:- The mean & standard deviation for the highest frequency beyond 4kHz in the onset spectrum of initial velars & alveolars for diff. minimal pairs for each of the subjects in the experimental group.

Adult target word	Mean highest peak beyond 4 kHz (in Hz) and SD: Subjects SB	DI	AM	MM	Group
cot	4488.0 (268.9)	5316.0 (1257.5)	5844.0 (1556.2)	5640.0 (801.5)	5322.0 (1129)
tot	4720.0 (475.0)	5968.0 (647.1)	5042.0 (685.9)	5272.0 (948.0)	5250.5 (803.1)
coffee	4712.0 (517.2)	5260.0 (570.9)	5710.0 (1535.8)	5560.0 (349.9)	5291.1 (852.6)
toffee	4660.0 (418.9)	4848.0 (814.6)	4852.0 (486.1)	6010.0 (1156.3)	5065.6 (868.6)
cop	4720.0 (558.1)	5160.0 (1056.0)	6384.0 (1137.9)	6056.0 (1791.9)	5625.3 (1324.7)
top	4808.0 (724.1)	4912.0 (781.5)	4712.0 (422.3)	5264.0 (597.1)	4294.0 (630.4)
cock	5104.0 (904.5)	4900.0 (748.3)	6596.0 (1347.3)	5944.0 (1246.3)	5636.0 (1218.1)
tock	4768.0 (216.5)	6710.0 (806.2)	4352.0 (194.7)	5780.0 (525.0)	5333.7 (1010.6)

Table A1.7:- The Mean & SD of highest frequency peak beyond 4kHz in the spectrum of initial velars & alveolars for each of the subjects in the experimental group.

Adult target initial consonant	Mean highest peak in Hz.and SD				
	S.B.	A.M.	D.I.	M.M.	Group
/k/	4757.9 (603.0)	6155.8 (1327.4)	5153.7 (897.6)	5800.0 (1099.4)	5472.6 (1137.7)
/t/	4743.2 (457.5)	4739.5 (511.4)	5551.6 (1040.2)	5559.0 (817.8)	5143.0 (835.1)

Table- A1.8:- The Mean & standard deviation of VOT of initial velars & alveolars for different minimal pairs for each of the subjects in the experimental group.

Adult target word	Mean VOT (in Sec.) and standard deviation				
	Subjects				
	SB	AM	DI	MM	Group
cot	.1 (.02)	.106 (.026)	.132 (.07)	.086 (.016)	0.105 (.042)
tot	.09 (.02)	.122 (.008)	.101 (.02)	.067 (.004)	0.094 (.024)
coffee	.163 (.23)	.118 (.005)	.09 (.06)	.074 (.028)	0.112 (.122)
toffee	.073 (.03)	.104 (.014)	.05 (.03)	.086 (.032)	0.079 (.032)
cop	.09 (.009)	.100 (.041)	.12 (.04)	.074 (.028)	0.94 (.035)
top	.133 (.03)	.109 (.020)	.09 (.01)	.086 (.028)	0.105 (.028)
cock	.086 (.039)	.088 (.036)	.131 (.046)	.23 (.37)	0.133 (.181)
tock	.086 (.031)	.081 (.044)	.093 (.012)	.09 (.06)	0.086 (.035)

and .072sec. (SD=33.2) for alveolars. The mean and SD of VOT for each minimal pair attempted by each child with velar fronting is given in table A1.8, along with group means for each word. The individual mean VOT and SD for attempted /k/~/t/ contrast are given in table A1.9. and in the form of a graph in figure A1.2. The results of completely randomised ANOVA for difference between the two sound type for mean VOT is given in table A1.11.

Table A1.10 :- The results of completely randomised ANOVA for the dependent variable, highest frequency peak beyond 4kHz in the onset spectrum for the various sources of variation.

Source of Variation	Sum of Squares	df	Mean Square	F	Signif of F
Main Effects	4156279.3	1	4156279.3	4.146	.043
Sound type	4156279.3	1	4156279.3	4.146	.043
Explained	4156279.3	1	4156279.3	4.146	.043
Residual	151367286.7	151	1002432.3		

Table A1.11 :- The results of completely randomised ANOVA for **voice onset time** measurements for the various sources of variation.

Source of Variation	Sum of Squares	df	Mean Square	F	Signif of F
Main Effects	.015	1	.015	2.266	.134
SD	.015	1	.015	2.266	.134
Explained	.015	1	.015	2.266	.134
Residual	1.017	151	.007		

Table-A1.9:- The Mean & SD of VOT of initial velars & alveolars for the subjects in the experimental group.

Adult target initial consonant	Mean VOT (in Sec.) and standard deviation				
	S.B.	A.M.	D.I.	M.M.	Group
/k/	0.108 (.12)	0.114 (.03)	0.147 (.19)	0.080 (.03)	.11 (.11)
/t/	0.095 (.03)	0.107 (.02)	0.083 (.04)	0.080 (.29)	.09 (.03)

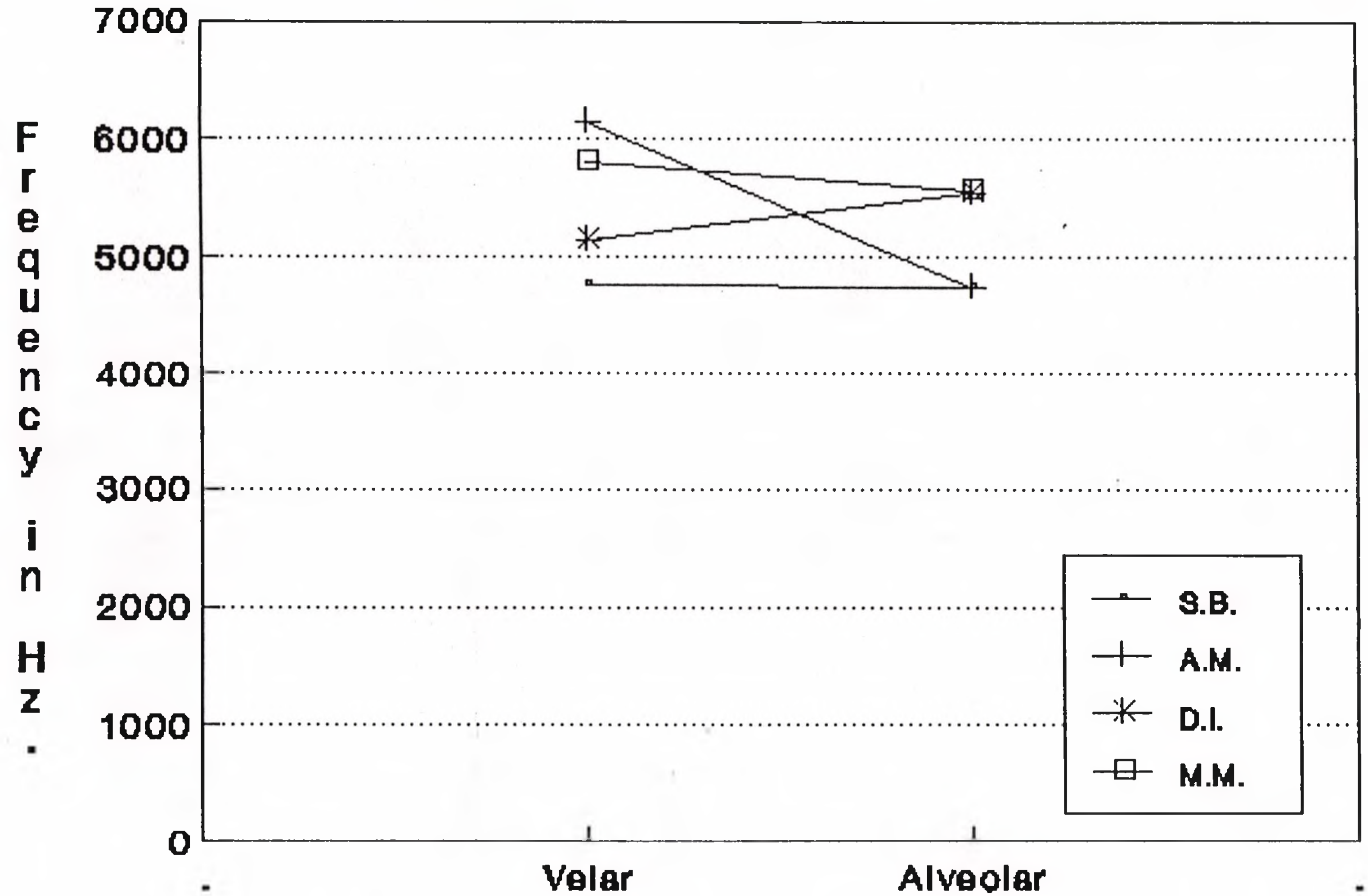

Fig. A1.1 - Mean highest frequency peak beyond 4 kHz for each subject separately for their attempted velar and alveolar initial words attempted by each subject with velar fronting.

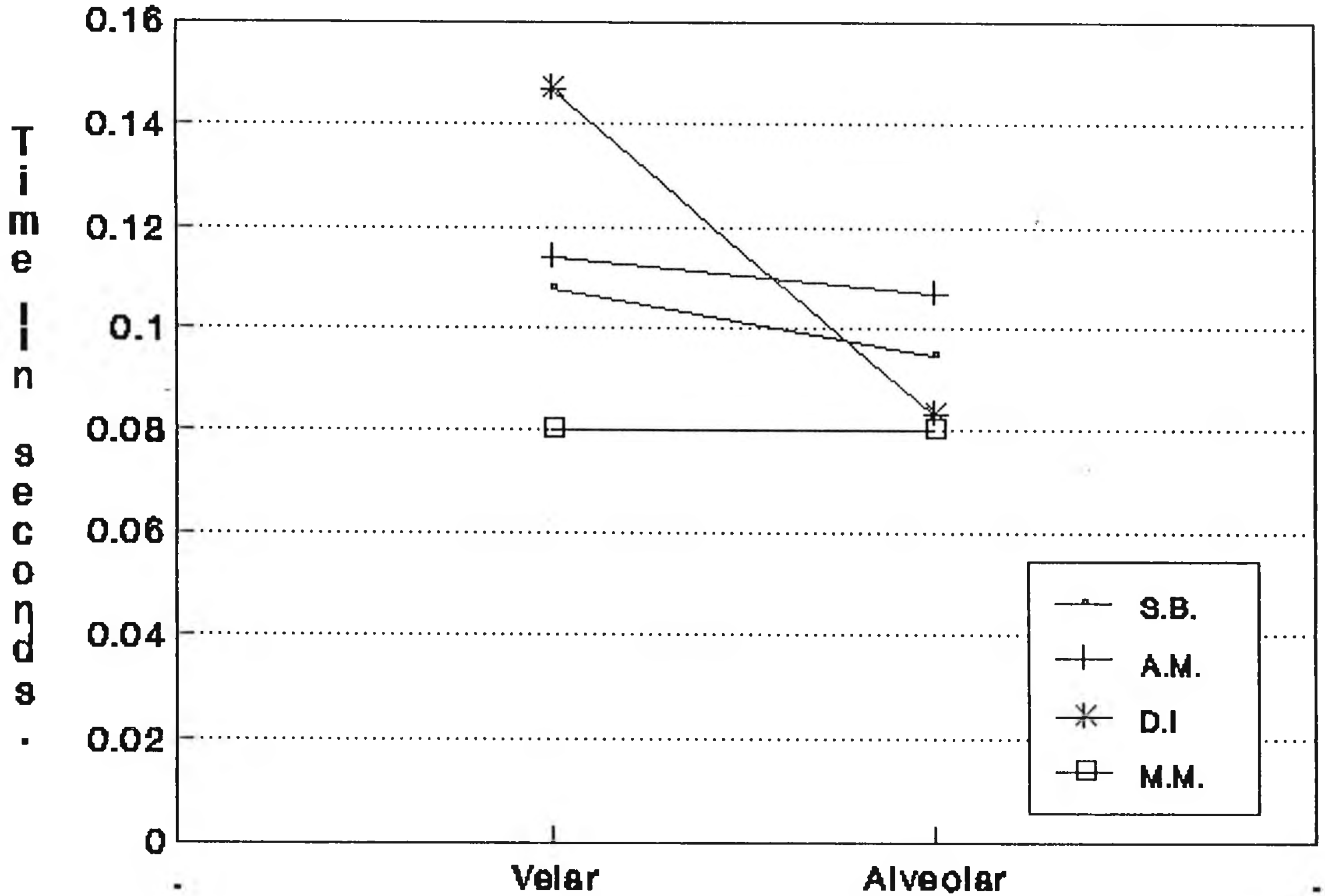

Fig. A1.2 - Mean VOT for each subject separately for their attempted velar and alveolar initial words attempted by each subject with velar fronting.

8.4 Discussion

When a child misarticulates target /k/, the usual result is a front articulation, which is perceived by adult listeners as /t/. Thus /t/~/k/ is lost, both appearing to be [t] and homophony of /t/~/k/ minimal pairs results. The main focus of the study was to ascertain whether velar misarticulating children acoustically mark their productions and whether they demonstrate auditory sensitivity to possible allophonic differences in their repertoire. The perception of velars and alveolars by velar misarticulating children in this study appears to be similar to error sound perception by children misarticulating other categories of speech sounds , for example /r/ (Hoffman, 1983). The accurate identification of velars/alveolars in stimulus words spoken by adults, indicates that none of the velar misarticulating children had difficulty perceiving contrasts in adult production. Perceptual differences appear to emerge in tape-recorded stimulus word spoken by the misarticulating child (that is, self perception). Although the overall identification score of velar misarticulating children indicates a high degree of accuracy in identification of their errors, (perceived as homophonous by adults), analysis of identification scores indicate that they have equal difficulty in identifying correctly produced alveolars and incorrect velars (Table A1.1: row 2 and 3). Such a pattern has been reported by other researchers investigating other production errors such as that of approximant contrasts (Hoffman, 1983; Chaney 1988) fricative contrasts (Wilcox & Stephen, 1982) and to a limited extent velar contrasts (Young & Gilbert, 1988). Although the trained listeners obtained similar group means as misarticulating children, error analysis in Table B clearly indicates that these high scores were due to a trend towards selection of /t/ initial words to most stimuli. Only in the case of subject A.M., the adult and velar misarticulating child appear to be identifying the words in a similar manner. Furthermore, adult listeners made more between minimal pair confusion , for example top for cop, than across minimal pairs , for example top for cock. Thus adult listeners were not finding difficulty in identifying the final consonants. From the results of the perceptual experiment it becomes apparent that velar-misarticulating children use different listening strategies for identifying self-spoken velars and alveolars as compared to adult listeners identification of the same stimulus material. This may be due to a poorly defined /k/~/t/ perceptual boundary. However, such a conclusion does not explain why the direction of misarticulation is more commonly toward alveolar/velar substitution than vise versa. It would be interesting to ascertain the nature of velar error production in languages which have more points of articulation in stop consonants than English , for example Indian languages have bilabial, dental, retroflex and velar stops.

Together with the template matching approach to spectral analysis this study measured two further acoustic features namely highest peak in spectra and VOT of initial consonants. Two stimuli which are perceived as different may be expected to be acoustically different. Since the perceptual experiment reveals that children with velar fronting may be perceiving the two minimal pairs differently from the way in which trained adults do, analysis was conducted to ascertain whether differences in the three acoustic measures could account for the children's perceptual confusion in their production errors

8.4.1 a) **<u>Onset spectra:-</u>**

Since the onset spectra was derived from the first 26ms. of the waveform it may be assumed to reflect articulatory dynamics within this time frame. On visual inspection of the shape of the onset spectra, it became apparent that normal speaking children were extremely consistent in the production of the initial 26 ms. of initial consonants. The same consistent spectral pattern was repeated every time the velar or alveolar initial word had to be produced. In the template matching approach it was difficult to quantify this consistency for comparison with average spectra of children with velar fronting. However, the Stevens-Blumstein template diffuse-rising was not effective in separating the velars from the alveolar. The poor hit rate by the Stevens-Blumstein templates for correct production of alveolars and velars by normal children in this study is in agreement with the findings reported by other studies (Chapin, Tseng, & Liberman, 1982; Hewlett, 1988; Forrest, Weismer, Hodge, Dinnsen & Elbert, 1990). Perhaps the differences in method of obtaining onset spectrum in this study may have contributed partly to the poor scores, since Stevens-Blumstein (1978) employed the LPC method for deriving the onset spectrum, while FFT principles were employed in this study. However minor adjustment to the template did not increase its accuracy.

The template proposed by Hewlett (1988) with some modifications appears to be effective in differentiating the alveolars and velars in the stimulus word articulated by normal children. On visual inspection of the shape of the onset spectrum of stimulus words produced by misarticulating children, the consistency in production of the initial 26ms. in normals, was not observed in the misarticulating children. This is in agreement with the findings of Forrest et al, (1990), who observed greater variability in the in the FFT based time-history movements over initial 40 ms. of the VOT interval in initial voiceless stops produced by children with velar fronting. The acceptance rate of /k/ and /t/ onset spectra by the modified Hewlett template indicates that the /k/-templates were more effective at differentiation than the /t/ templates (table A1.5). One surprising observation emerged. Even where target /t/ was involved and the fronting child articulated

[t], the resultant spectra failed to match the alveolar templates. It may be concluded from this that misarticulating children produced the first 26 ms. of the consonant differently from normal children in both velars and alveolars. However, caution needs to be exercised in drawing conclusion based on acceptance/rejection of onset spectrum by the modified Hewlett template as these templates have not yet been validated as reflecting the acoustic cues for place of articulation in stops. Furthermore, the fit to a template provides little information on production strategies used by these children. In general there appears to be a need to measure both acoustic cues for place of articulation in stops that is, onset spectra and formant transitions as F2 measures would give better information on relative cavity size anterior to the source. Furthermore, perceptual experiments, such as listening to stimulus words in which the aperiodic transition segment has been edited, may be useful in ascertaining the relative importance of aperiodic burst and the transition elements of the replacing sound and alveolar consonants in velar misarticulating children.

8.4.2 b) <u>**Voice onset time:**</u>-

Longer VOT has been reported for velar consonants as compared to bilabials and alveolars (Lisker & Abramson, 1964; Kewley-Port, 1983 & Young & Gilbert, 1988). Fant (1973) reported a mean difference of 20ms. for aspirated voiceless velars and alveolars. Young and Gilbert, (1988) observed a mean increase of 8.3ms. in VOT for target words <u>top</u>(0.0713) and <u>cop</u>(0.0706) for normal production, which however did not reach statistical significance. Comparatively the subjects in this appear to be having longer VOT than those obtained for by normal children in the studies of Young and Gilbert, (1988) and Zlattin and Koenigsknecht, (1976). It has been speculated that velar misarticulating children may maintain contrasts in acoustic features which are not directly related to place of articulation acoustic information , for example duration of following vowel, VOT, etc (Weismer,1984; Hewlett, 1988; Young & Gilbert, 1988). The mean VOTs across all misarticulating subjects indicate difference of 0.02 sec. (Table A1.9) which is comparable to Fant's(1973) findings. On application of ANOVA this difference did not reach statistical significance (Table A1.11). However there appears to be considerable difference across subjects. Subjects S.B. and D.I., appear to be maintaining substantially larger VOTs for velars (That is, a mean difference of .013 and .064 sec. respectively) while subject A.M. and M.M. appear to be maintaining negligible VOT differences between the two categories of stops (Fig.A1.1). The difference of 0.064 sec. for D.I. is considerably greater than that reported by Hewlett(1988) for his subject CS2. However, on application of the Scheffee test for significance the difference in VOT for D.I.'s production for the two sound types did not reach statistical significance. On inspecting VOT values for the mean for each stimulus word (Table A1.8) except for subject D.I. there is no specific preference for larger VOTs for velars. However it must be noted that the perception experiments conducted in this study are not adequate for ascertaining whether S.B. and D.I. were auditorily sensitive to the VOT differences.

8.4.3 c) <u>Highest peak above 4kHz:</u>-

The highest peak above 4 kHz. appears to have given better results. The subjects appear to be consistently maintaining difference for velar and alveolar minimal pairs. From figure A1.2, subject AM appears to maintain the most difference with higher values for velars. Subject DI appears to have reversed the trend.

It may be observed in table A1.6 that for higher that for each minimal pair higher frequency was obtained for the velars as opposed to alveolar initial words. The F-ratio of 5.116 obtained for the difference between means for sound type effect was found to be significant at the .025 level (Table A1.10). Although the acoustic theory of speech production predicts a dominance of high-frequency energy when the cavity in front of the source is smaller, it is difficult to ascertain whether a mean difference of 329.64 Hz. actually reflects a slightly forward point of articulation in case of target velar production. The formant 2 transition has been found to reflect the place of articulation rather than the highest frequency above 4 kHz measured by Hewlett (1988) (Liberman et al, 1967;

Fant, 1973). Fant's (1973) observation of a higher frequency peak in transient region for Swedish alveolars compared to velars was for formant 2 peak. Indeed acoustic measurement strategies need to be developed which are better reflectors of articulatory dynamics in child production than the measures developed by Stevens and Blumstein (1978) and those employed by Hewlett (1988). Such strategies are being developed as a part of research into velar fronting in languages with more contrastive place of articulation in plosive consonants , for example Indoaryan languages. In conclusion the results of the two experiments indicate that:-

1) Some velar misarticulating children have equal difficulty in identifying both velar errors and alveolars in their own production.
2) The onset spectra of velar and alveolar initial words spoken by misarticulating children neither resemble the alveolar or the velar templates employed in this study.
3) Measurement of both onset spectra and formant transition in velar errors and alveolar production by velar misarticulating children is essential for ascertaining whether these children make allophonic differences in their velar/alveolar initial minimal word pairs.
4) A subset of velar misarticulating children have no difficulty in identifying velars and

alveolars in adult speech.

5) Both voiced and voiceless velar/alveolar cognates as stimulus material are not readily accommodated in analysis of onset spectra.

6) No significant differences in VOT were maintained by misarticulating children for their alveolar and replacing sounds for velars.

7) The Blumstein-Stevens template is not adequate for differentiating alveolars and velar onset spectrum derived with the Kay Elemetrics sonograph workstation.

-OOO-

9 APPENDIX II: ANOVA Tables

Results of completely randomised ANOVA applied to acoustic measures obtained from o/p of subjects from Control group I, and Experimental group.

9.1 ANOVA applied to Data from control group I.:-

Results of Analysis of variance applied to acoustic data obtained from /k^{h}alI/ and /t̠^{h}alI/ spoken by subjects in **control group** I are presented in the following tables. In each table the main effects of [k^h]~[t̠^{h}] minimal pair and Subject along with the interaction effect are presented for the different acoustic measures as the dependent variable.

Table A2.1.1:- ANOVA table for the dependent variable F2tr and the main effects of [k^h]~[t̠^{h}] minimal pair and Subject along with the interaction effect.

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	16811612.67	5	3362322.534	53.615	.000
Subject	3974440.26	4	993610.065	15.844	.000
Minimal pair	12837172.41	1	12837172.410	204.699	.000
2-way	1936509.74	4	484127.435	7.720	.000
Interactions	1936509.74	4	484127.435	7.720	.000
Explained	18748122.41	9	2083124.712	33.217	.000
Residual	5644131.70	90	62712.574		
Total	24392254.11	99	246386.405		

Table A2.1.2:- ANOVA table for the dependent variable **F2fr** and the main effects of [k^h]~[$\underline{t}^h$] minimal pair and Subject along with the interaction effect.

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	9412299.540	5	1882459.908	31.074	.000
Subject	3341003.540	4	835250.885	13.788	.000
Minimal pair	6071296.000	1	6071296.000	100.221	.000
2-way	394014.500	4	98503.625	1.626	.175
Interactions	394014.500	4	98503.625	1.626	.175
Explained	9806314.040	9	1089590.449	17.986	.000
Residual	5452121.200	90	60579.124		
Total	15258435.240	99	154125.608		

Table A2.1.3:- ANOVA table for the dependent variable **F2as** and the main effects of $[k^h]\sim[\underline{t}^h]$ minimal pair and Subject along with the interaction effect.

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	5568222.800	5	1113644.560	62.635	.000
Subject	3243207.760	4	810801.940	45.602	.000
Minimal pair	2325015.040	1	2325015.040	130.766	.000
2-way	347132.760	4	86783.190	4.881	.001
Interactions	347132.760	4	86783.190	4.881	.001
Explained	5915355.560	9	657261.729	36.966	.000
Residual	1600200.600	90	17780.007		
Total	7515556.160	99	75914.709		

Table A2.1.4:- ANOVA table for the dependent variable **F2 of vowel [a]** and the main effects of $[k^h]\sim[\underline{t}^h]$ minimal pair and Subject along with the interaction effect.

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	2174026.140	5	434805.228	25.933	.000
Subject	1889723.900	4	472430.975	28.177	.000
Minimal pair	284302.240	1	284302.240	16.956	.000
2-way	200465.860	4	50116.465	2.989	.023
Interaction	200465.860	4	50116.465	2.989	.023
Explained	2374492.000	9	263832.444	15.735	.000
Residual	1509005.000	90	16766.722		
Total	3883497.000	99	39227.242		

Table A2.1.5:- ANOVA table for the dependent variable **Dtr** and the main effects of $[k^h]\sim[\underline{t}^h]$ minimal pair and Subject along with the interaction effect.

Sources of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	144.02	5	28.80	5.54	.000
Subject	122.86	4	30.71	5.91	.000
Minimal pair	21.16	1	21.16	4.07	.046
2-way	16.54	4	4.13	.79	.531
Interactions	16.54	4	4.13	.79	.531
Explained	160.56	9	17.84	3.43	.001
Residual	467.20	90	5.19		
Total	627.76	99	6.34		

Table A2.1.6:- ANOVA table for the dependent variable **Das** and the main effects of $[k^h]\sim[\underline{t}^h]$ minimal pair and Subject along with the interaction effect.

Sources of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	25081.30	5	5016.26	12.34	.000
Subject	19426.26	4	4856.56	11.94	.000
Minimal pair	5655.04	1	5655.04	13.91	.000
2-way	13176.26	4	3294.06	8.10	.000
Interaction	13176.26	4	3294.06	8.10	.000
Explained	38257.56	9	4250.84	10.45	.000
Residual	36580.20	90	406.44		
Total	74837.76	99	755.93		

Table A2.1.7:- ANOVA table for the dependent variable **VOT** and the main effects of [k^h]~[$\underline{t}^h$] minimal pair and Subject along with the interaction effect.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	44129.50	5	8825.90	17.70	.000
Subject	28253.50	4	7063.37	14.16	.000
Minimal pair	15876.00	1	15876.00	31.83	.000
2-way	2724.90	4	681.22	1.36	.252
Interactions	2724.90	4	681.22	1.36	.252
Explained	46854.40	9	5206.04	10.44	.000
Residual	44878.60	90	498.65		
Total	91733.00	99	926.59		

Table A2.1.8:- ANOVA table for the dependent variable **duration of vowel [a]** and the main effects of [k^h]~[$\underline{t}^h$] minimal pair and Subject along with the interaction effect.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	32094.28	5	6418.85	7.82	.000
Subject	31725.64	4	7931.41	9.66	.000
Minimal pair	368.64	1	368.64	.44	.504
2-way	9195.16	4	2298.79	2.80	.030
Interactions	9195.16	4	2298.79	2.80	.030
Explained	41289.44	9	4587.71	5.59	.000
Residual	73835.80	90	820.39		
Total	115125.24	99	1162.881		

Table A2.1.9:- ANOVA table for the dependent variable **duration of word** and the main effects of [k^h]~[$\underline{t}^h$] minimal pair and Subject along with the interaction effect.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	618159.91	5	123631.98	18.32	.000
Subject	611353.66	4	152838.41	22.65	.000
Minimal pair	6806.25	1	6806.25	1.00	.318
2-way	5215.30	4	1303.82	.19	.941
Interaction	5215.30	4	1303.82	.19	.941
Explained	623375.21	9	69263.91	10.26	.000
Residual	607058.90	90	6745.09		
Total	1230434.11	99	12428.62		

Table A2.1.10:- ANOVA table for the dependent variable **fundamental frequency** and the main effects of [k^h]~[$\underline{t}^h$] minimal pair and Subject along with the interaction effect.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	75560.35	5	15112.07	57.97	.000
Subject	75307.54	4	18826.88	72.22	.000
Minimal pair	252.81	1	252.81	.97	.327
2-way	1009.14	4	252.28	.96	.429
Interactions	1009.14	4	252.28	.96	.429
Explained	76569.49	9	8507.72	32.63	.000
Residual	23459.50	90	260.66		
Total	100028.99	99	1010.39		

9.2 <u>ANOVA applied to Data from Experimental group:</u>-

Results of Analysis of variance applied to acoustic data obtained from /k^halI/ and /$\underline{t}^h$alI/ spoken by subjects in **Experimental group** are presented in the following tables. In each table the main effects of [k^h]~[$\underline{t}^h$] minimal pair and Subject along with the interaction effect are presented for the different acoustic measures as the dependent variable.

<u>**Table A2.2.1:**</u>- ANOVA table for the dependent variable F2tr and the main effects of [k^h]~[$\underline{t}^h$] minimal pair and Subject along with the interaction effect for data obtained from experimental group.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	4589529.16	7	655647.02	5.65	.00
Subject	4583123.38	6	763853.89	6.59	.00
Minimal pair	6405.77	1	6405.77	.05	.81
2-way	209318.47	6	34886.41	.30	.93
Interactions	209318.47	6	34886.41	.30	.93
Explained	4798847.63	13	369142.12	3.18	.00
Residual	14598598.50	126	115861.89		
Total	19397446.13	139	139549.97		

Table A2.2.2:- ANOVA table for the dependent variable **F2fr** and the main effects of [k^h]~[$\underline{t}^h$] minimal pair and Subject along with the interaction effect for data obtained from experimental group.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	2325011.53	7	332144.50	3.09	.01
Subject	2323532.78	6	387255.46	3.60	.002
Minimal pair	1478.75	1	1478.75	.01	.90
2-way	1317009.30	6	219501.55	2.04	.06
Interactions	1317009.30	6	219501.55	2.04	.06
Explained	3642020.83	13	280155.44	2.61	.003
Residual	13524053.30	126	107333.75		
Total	17166074.13	139	123496.93		

Table A2.2.3:- ANOVA table for the dependent variable **F2as** and the main effects of [k^h]~[$\underline{t}^h$] minimal pair and Subject along with the interaction effectfor data obtained from experimental group.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	3283273.15	7	469039.02	12.59	.00
Subject	3268890.57	6	544815.09	14.62	.00
Minimal pair	14382.57	1	14382.57	.38	.53
2-way	145550.77	6	24258.46	.65	.68
Interactions	145550.77	6	24258.46	.65	.68
Explained	3428823.92	13	263755.68	7.08	.00
Residual	4692398.50	126	37241.25		
Total	8121222.42	139	58426.06		

Table A2.2.4:- ANOVA table for the dependent variable **F2 of vowel [a]** and the main effects of $[k^h]$~$[\underline{t}^h]$ minimal pair and subject along with the interaction effect for data obtained from experimental group.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	2400645.80	7	342949.40	10.04	.00
Subject	2355931.48	6	392655.24	11.50	.00
Minimal pair	44714.31	1	44714.31	1.31	.25
2-way	328827.28	6	54804.54	1.60	.15
Interactions	328827.28	6	54804.54	1.60	.15
Explained	2729473.08	13	209959.46	6.15	.00
Residual	4300412.80	126	34130.26		
Total	7029885.88	139	50574.71		

Table A2.2.5:- ANOVA table for the dependent variable **Dtr** and the main effects of $[k^h]$~$[\underline{t}^h]$ minimal pair and Subject along with the interaction effect for data obtained from experimental group.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	735.76	7	105.10	5.75	.00
Subject	735.15	6	122.52	6.70	.00
Minimal pair	.60	1	.60	.03	.85
2-way	39.52	6	6.58	.36	.90
Interactions	39.52	6	6.58	.36	.90
Explained	775.28	13	59.63	3.26	.00
Residual	2301.57	126	18.26		
Total	3076.86	139	22.13		

Table A2.2.6:- ANOVA table for the dependent variable **Das** and the main effects of $[k^h] \sim [\underline{t}^h]$ minimal pair and Subject along with the interaction effect for data obtained from experimental group.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	75860.33	7	10837.19	26.03	.00
Subject	75539.00	6	12589.83	30.24	.00
Minimal pair	321.33	1	321.33	.77	.38
2-way	10507.74	6	1751.29	4.20	.001
Interactions	10507.74	6	1751.29	4.20	.001
Explained	86368.08	13	6643.69	15.95	.00
Residual	52456.08	126	416.31		
Total	138824.17	139	998.73		

Table A2.2.7:- ANOVA table for the dependent variable **VOT** and the main effects of $[k^h] \sim [\underline{t}^h]$ minimal pair and Subject along with the interaction effect for data obtained from experimental group.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	80293.02	7	11470.43	27.03	.00
Subject	80046.97	6	13341.16	31.44	.00
Minimal pair	246.05	1	246.05	.58	.45
2-way	10744.40	6	1790.73	4.22	.001
Interactions	10744.40	6	1790.73	4.22	.001
Explained	91037.43	13	7002.88	16.50	.00
Residual	53456.30	126	424.25		
Total	144493.73	139	1039.52		

Table A2.2.8:- ANOVA table for the dependent variable **duration of vowel [a]** and the main effects of $[k^h] \sim [\underline{t}^h]$ minimal pair and Subject along with the interaction effect for data obtained from experimental group.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	149526.62	7	21360.94	15.16	.00
Subject	141207.53	6	23534.59	16.70	.00
Minimal pair	8319.09	1	8319.09	5.90	.02
2-way	10931.23	6	1821.87	1.29	.27
Interactions	10931.23	6	1821.87	1.29	.27
Explained	160457.86	13	12342.91	8.76	.00
Residual	177487.44	126	1408.63		
Total	337945.30	139	2431.26		

Table A2.2.9:- ANOVA table for the dependent variable **duration of word** and the main effects of $[k^h] \sim [\underline{t}^h]$ minimal pair and Subject along with the interaction effect for data obtained from experimental group.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	1408420.76	7	201202.96	37.57	.00
Subject	1386643.15	6	231107.19	43.15	.00
Minimal pair	21777.60	1	21777.60	4.06	.05
2-way	33063.12	6	5510.52	1.02	.41
Interactions	33063.12	6	5510.52	1.02	.41
Explained	1441483.89	13	110883.37	20.70	.00
Residual	674760.51	126	5355.24		
Total	2116244.41	139	15224.78		

Table A2.2.10:- ANOVA table for the dependent variable **fundamental frequency** and the main effects of $[k^h]$~$[\underline{t}^h]$ minimal pair and Subject along with the interaction effect for data obtained from experimental group.

Source Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	230438.06	7	32919.72	42.50	.00
Subject	230324.48	6	38387.41	49.56	.00
Minimal pair	113.58	1	113.58	.14	.70
2-way	4412.53	6	735.42	.95	.46
Interactions	4412.53	6	735.42	.95	.46
Explained	234850.59	13	18065.43	23.32	.00
Residual	97582.34	126	774.46		
Total	332432.94	139	2391.60		

10 APPENDIX III: Discriminant Analysis.

Results of Discriminant analysis applied to acoustic measures obtained from o/p of subjects from control group I and Experimental group.

10.1 Discriminant analysis application to data obtained from Control group I:-

Table 3.1.1:-Pooled Within-Groups Correlation Matrix for the various acoustic variables measures on velar and dental initial words spoken by subjects in control group I.

	F2tr	Ffr	Fas	F2[a]	Dtr
F2tr	1.000				
Ffr	.617	1.000			
Fas	.385	.536	1.000		
F2[a]	.371	.460	.464	1.000	
Dtr	.123	-.115	-.236	-.276	1.000
Das	.301	.235	.085	.201	-.102
VOT	-.276	-.280	-.467	-.286	.133
Dvwl	-.096	-.079	-.066	.154	-.283
Dwrd	-.279	-.195	-.278	-.021	-.109
FO	.263	.321	.528	.594	-.365

	Das	VOT	Dvwl	Dwrd	DFO
Das	1.000				
VOT	.290	1.000			
Dvwl	.087	-.020	1.000		
Dwrd	.216	.495	.389	1.000	
FO	.321	-.139	.209	.076	1.000

Table A3.1.2:- Wilks' Lambda (U-statistic) and univariate F-ratio with 1 and 98 degrees of freedom derived for the various acoustic measures.

Acoustic Variable	Wilks' Lambda	F	Significance
F2tr	.47372	108.9	.0000
Ffr	.60210	64.76	.0000
Fas	.69064	43.90	.0000
F2[a]	.92679	7.741	.0065
Dtr	.96629	3.419	.0675
Das	.92444	8.011	.0056
VOT	.82693	20.51	.0000
Dvwl	.99680	.3148	.5760
Dwrd	.99447	.5451	.4621
FO	.99747	.2483	.6194

Table A3.1.3:-Standardised Canonical Discriminant Function Coefficients for the various acoustic variables measured.

Acoustic variables	FUNC 1
F2tr	.98668
Ffr	.11356
Fas	.40183
F2[a]	-.15766
Dtr	-.31718
Das	-.56098
VOT	.10581
Dvwl	.07626
Dwrd	.38715
FO	-.34681

Table A3.1.4:- Structure Matrix for the pooled-within-groups correlations between discriminating acoustic variables measured and canonical discriminant functions. (Variables ordered by size of correlation within function)

Acoustic Varaibles	FUNC 1
F2tr	.70924
Ffr	.54701
Fas	.45035
VOT	-.30783
Das	-.19238
F2[a]	.18912
Dtr	-.12568
Dwrd	-.05018
Dvwl	.03814
FO	.03387

Table A3.1.5:-The canonical discriminant function for the two sound groups.

Canonical Discriminant Functions

Fcn	Eigen value	Pct of Variance	Cum Pct	Canon-ical Corr		After Fcn	Wilks' Lambda	Chisq.	DF	Sig
					:	0	.312	108.4	10	.00
1*	2.21	100.0	100.0	.83	:					

* marks the 1 canonical discriminant functions remaining in the analysis.

10.2 Discriminant analysis application to data obtained from Experimental group :-

Table A3.2.1:-Pooled Within-Groups Correlation Matrix for the various acoustic variables measures on velar and dental initial words attempted by subjects in experimental group.

	F2tr	F2fr	F2as	F2[a]	Dtr
F2tr	1.00000				
Ffr	.31175	1.00000			
Fas	.30628	.24326	1.00000		
F2[a]	.19768	.18702	.48955	1.00000	
Dtr	-.10909	-.09424	-.12433	-.17444	1.00000
Das	-.08187	.01833	-.19405	-.21385	.06617
VOT	-.09430	.00640	-.20849	-.23360	.21209
Dvwl	-.12728	-.10919	-.08650	.00759	.11214
Dwrd	-.27847	-.24638	-.23828	-.11471	.23046
FO	.26523	.24949	.43122	.36261	-.12122

	Das	VOT	Dvwl	Dwrd	FO
Das	1.00000				
VOT	.98865	1.00000			
Dvwl	.01913	.03361	1.00000		
Dwrd	.31309	.33716	.52819	1.00000	
FO	.03498	.01623	-.07307	-.08680	1.00000

Table A3.2.2:- Wilks' Lambda (U-statistic) and univariate F-ratio with 1 and 138 degrees of freedom derived for the various acoustic measures obtained from experimental group.

Acoustic Variable	Wilks' Lambda	F	Significance
F2tr	.99967	.4559E-01	.8312
Ffr	.99991	.1189E-01	.9133
Fas	.99823	.2448	.6215
F2[a]	.99364	.8834	.3489
Dtr	.99980	.2712E-01	.8694
Das	.99769	.3202	.5724
VOT	.99830	.2354	.6283
Dvwl	.97538	3.483	.0641
Dwrd	.98971	1.435	.2330
FO	.99966	.4717E-01	.8284

Table A3.2.3:-Standardised Canonical Discriminant Function Coefficients for the various acoustic variables measures obtained from experimental group.

Acoustic Varaibles	FUNC 1
F2tr	.03402
Ffr	.12717
Fas	-.09369
F2[a]	-.59048
Dtr	-.09553
Das	-.48101
Dvwl	.65797
Dwrd	.28918
FO	.37929

Table A3.2.4:- Structure Matrix for the pooled-within-groups correlations between discriminating acoustic variables measures obtained from experimental group and their canonical discriminant functions. (Variables ordered by size of correlation within function)

Acoustic Varaibles	FUNC 1
F2tr	.74849
Ffr	.48042
Fas	-.37696
F2[a]	-.22694
Dtr	-.21496
Das	-.19845
VOT	.08710
Dvwl	-.08563
Dwrd	.06605
FO	-.04373

Table A3.2.5:-The canonical discriminant function for the two sound groups obtained from experimental group.

Fcn	Eigen value	Pct of Variance	Cum Pct	Canon-ical Corr		After Fcn	Wilks' Lambda	Chisq.	DF	Sig
					:	0	.957	5.88	9	.75
1*	.045	100.0	100.0	.207	:					

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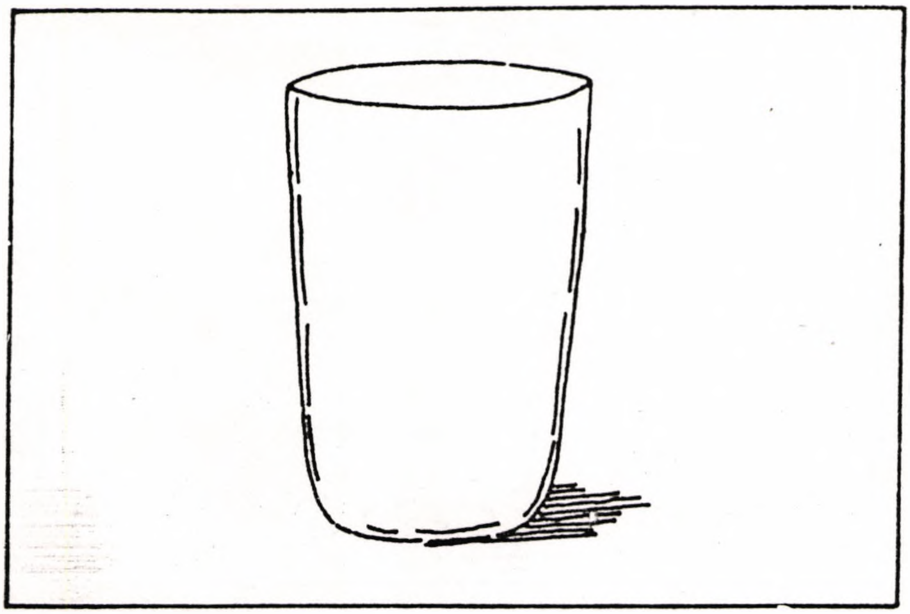
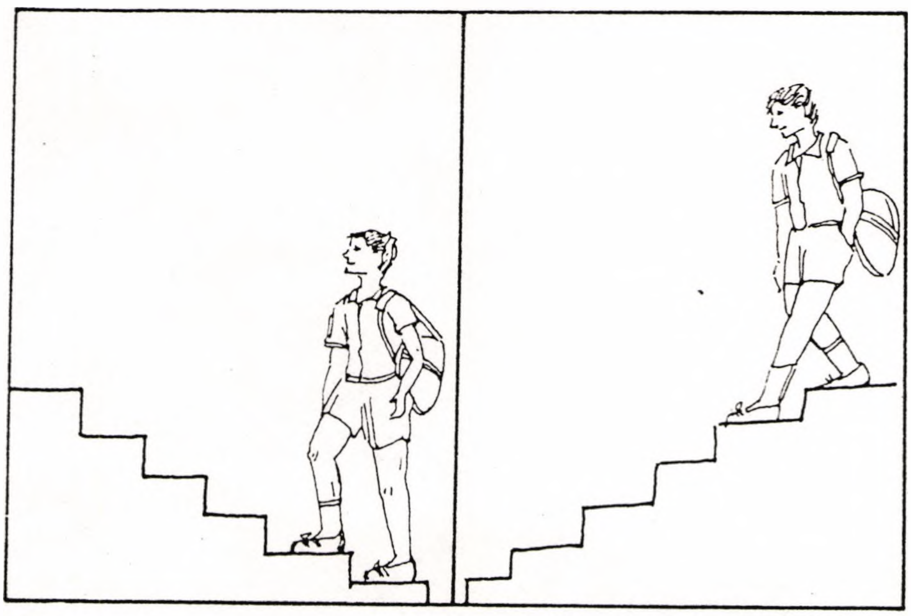
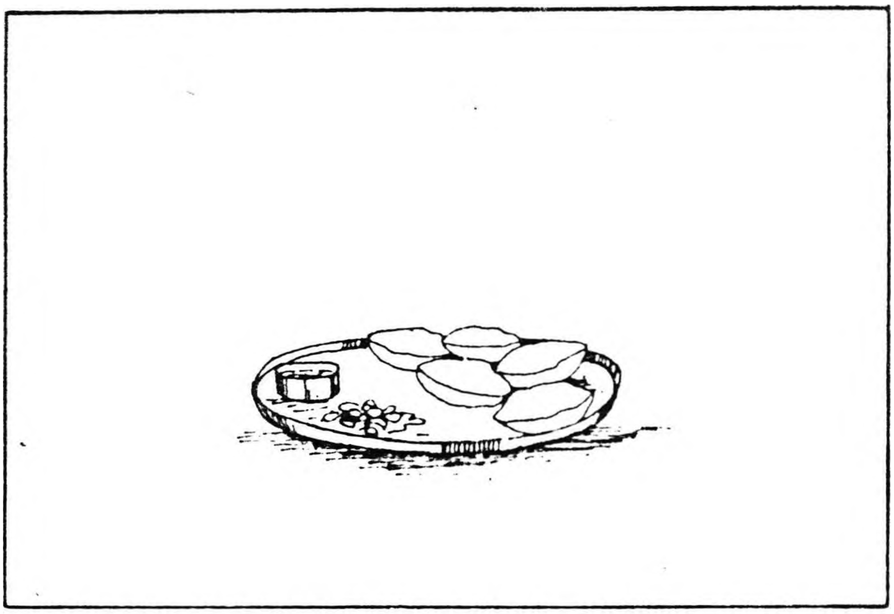
11 APPENDIX IV: Stimulus material



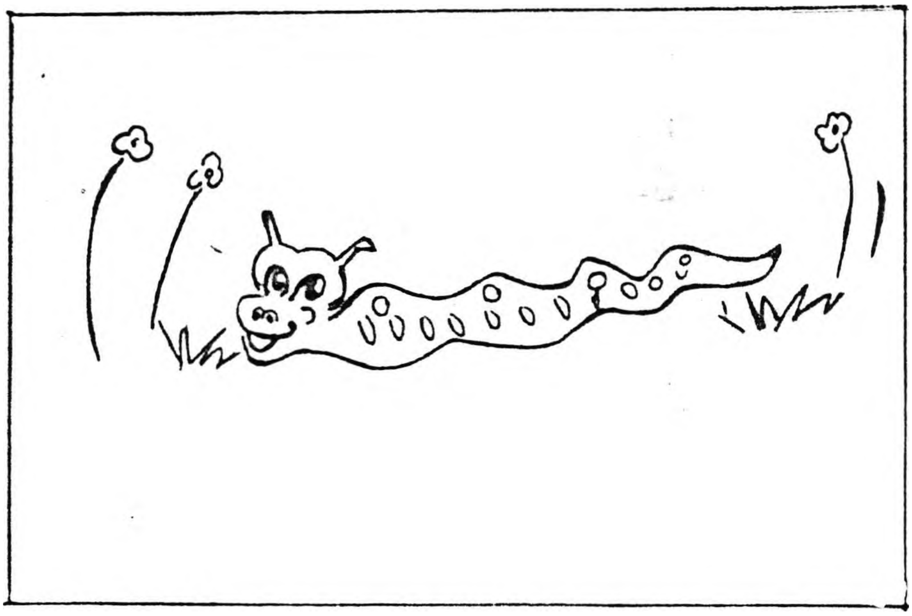
/k^halI/
(Hindi)



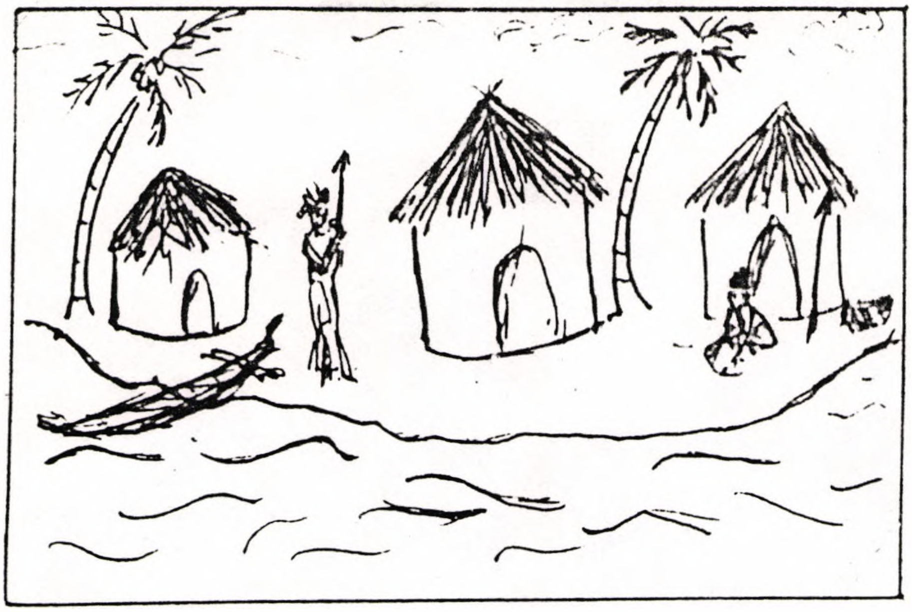
/k^halI/
(Marati)



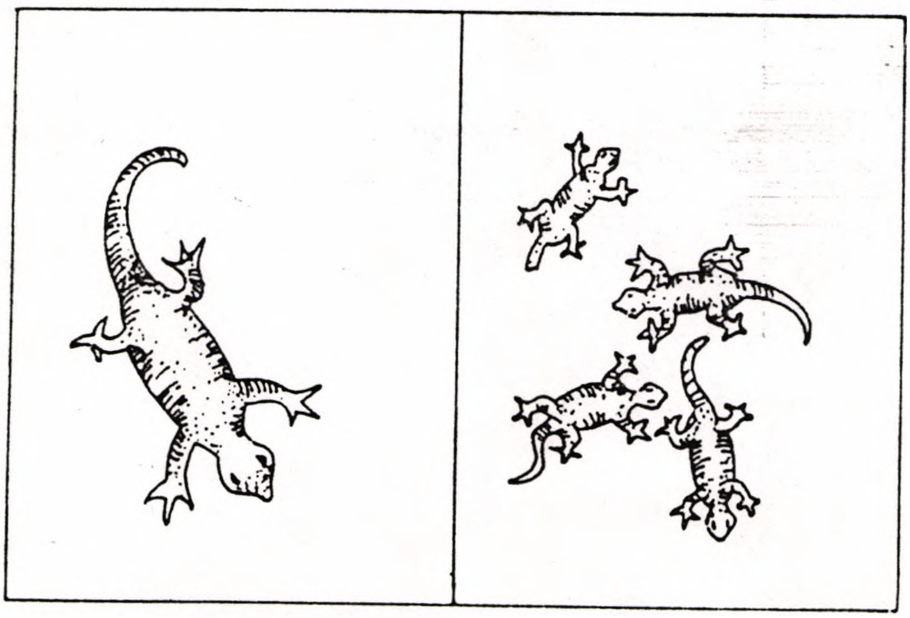
$/\underline{t}^{h}alI/$
(Common to Hindi & Marati)



/halI/ (non word)
(Common to Hindi & Marati)



/palI/
(Hindi)



/palI/
(Marati)

13 APPENDIX VI: Word list for testing velar production

Hindi

1.	पुस्तक	1. /pUst̲ʌk/	‘book’
2.	गंठी	2. /gʌnʈ^{h}i/	‘bell’
3.	छत्री	3. /tʃ^{h}t̲ri/	‘umbrella’
4.	बैंगन	4. /bængʌn/	‘egg-plant’
5.	किताब	5. /kIt̲ab/	‘book’
6.	कागज	6. /kagʌz/	‘paper’
7.	गाडी	7. /gadi/	‘vehicle’
8.	धागा	8. /d̲^{h}aga/	‘thread’
9.	अंगूठी	9. /ʌnguʈ^{h}i/	‘ring’
10.	पंखा	10. /pʌnk^{h}a/	‘fan’
11.	ऐनक	11. /ænʌk/	‘spectacles’
12.	तबला	12. /t̲ʌbʌla/	‘drum’
13.	थैली	13. /t̲^{h}æli/	‘bag’
14.	बाल्टी	14. /balʈi/	‘bucket’
15.	राखी	15. /rak^{h}i/	‘talisman’
16.	औरत	16. /ɔrʌt̲/	‘lady’
17.	ताला	17. /t̲ala/	‘lock’
18.	चूडिया	18. /tʃudIia/	‘bangles’
19.	कार	19. /kar/	‘car’
20.	खचडा	20. /k^{h}ʌtʃʌda/	‘rubbish’
21.	घर	21. /g^{h}ʌr/	‘house’
22.	टोपी	22. /ʈopi/	‘hat’
23.	कंगी	23. /kʌngi/	‘comb’
24.	शंक	24. /ʃʌnk/	‘shell’
25.	लकडी	25. /lʌkd^{h}i/	‘stick’

Marati

1. पुस्तक
2. गंठी
3. छत्री
4. वांगी
5. पुस्तक
6. कागद
7. गाडी
8. धागा
9. अंगूठी
10. पंखा
11. चश्मा
12. तबला
13. पिशवि
14. बाल्दी
15. राखी
16. केश
17. कुलूप
18. बाँगडी
19. कार
20. खचडा
21. घर
22. टोपी
23. कंगुवा
24. शंक
25. लाकूड

1. /pUst̲ək/ ‘book’
2. /gənt^{h}i/ ‘bell’
3. /tʃ^{h}t̲ri/ ‘umbrella’
4. /vangi/ ‘egg-plant’
5. /kIlli/ ‘book’
6. /kagəd̲/ ‘paper’
7. /gadi/ ‘vehicle’
8. /d̲^{h}aga/ ‘thread’
9. /ənguʈ^{h}i/ ‘ring’
10. /pənk^{h}a/ ‘fan’
11. /tʃəsma/ ‘spectacles
12. /t̲əbəla/ ‘drum’
13. /pIʃvi/ ‘bag’
14. /bald̲i/ ‘bucket’
15. /rak^{h}i/ ‘talisman’
16. /keʃ/ ‘hair’
17. /kUlup/ ‘lock’
18. /bangədi/ ‘bangles’
19. /kar/ ‘car’
20. /k^{h}ətʃda/ ‘rubbish’
21. /g^{h}ər/ ‘house’
22. /ʈopi/ ‘hat’
23. /kangUa/ ‘comb’
24. /ʃənk/ ‘shell’
25. /lakud/ ‘stick’