EFFECT OF HEARING IMPAIRMENT AND NOISE ON PERCEPTION OF VOICING IN KANNADA

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A Dissertation Submitted in part fulfillment
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Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING
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May - 2005

CERTIFICATE

This is to certify that this dissertation entitled ***"Effect of Hearing Impairment and Noise on Perception of voicing in Kannada"*** is the bonafide work in part fulfillment for the degree of Master of Science (Audiology) of the student (Registration No. A0390011). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "***Effect of Hearing Impairment and Noise on Perception of voicing in Kannada***" is the result of my own study under the guidance of Dr. Asha Yathiraj, Reader & H.O.D., Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in any other university for the award of any diploma or degree.

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INTRODUCTION

Speech perception is defined as the process by which sensory evidence, generated by physical stimuli originating from a talker's speech movements, is used to arrive at decisions about the linguistic patterns those movements were intended to represent. Speech perception occurs within the large context of communication by spoken language (Boothroyd, 1993).

Speech sounds have been described as bundles of constituent distinctive features (Jakobson, Fant, & Halle, 1961; Chomsky & Halle, 1968; Ladefoged, 1971). For example, Jakobson, Fant and Halle (1961) have classified the speech sounds of English according to four categories, including (1) Place of articulatory constriction, (2) manner of production, (3) nasal-oral, and (4) voicing. The universality of the voicing feature is well-documented (Lotz, Abramson, Gerstman, Ingemann, & Nemser, 1960; Lisker & Abramson, 1964; Han & Weitzman, 1970). Lisker and Abramson (1964) demonstrated both acoustically and physiologically that there is a continuous dimension of voicing which is variably employed in many languages to establish differences between or among speech sound categories with the same manner of production (Abramson & Lisker, 1967).

Studies of phoneme occurrence in conversation have indicated that the voicing feature is a very prominent phonological distinction (Mines, Hanson, & Shoup, 1978). Investigations of stop consonants have identified many different acoustic features which are associated with the voicing contrast, including the presence or absence of a voice bar, contrastive closure and vowel durations, burst amplitude, duration and spectral extensiveness of the vowel formant transition, etc., (Delattre, 1958; Lisker & Abramson, 1964; Slis, 1970). The perceptual importance of each of the acoustic features described above can be examined through use of synthetic speech (Lisker, Cooper & Liberman, 1962). Simultaneous analysis of the corresponding feature from individual utterances allows for a comparison between subjects' behaviour in speech perception and production (Lorge, 1967). Abramson and Lisker (1967), Malecot (1968), Slis and Cohen (1969), Netsell (1969), and Sawashima, Abramson, Cooper, and Lisker (1970), among others, have examined various aspects of the articulatory regulation of voicing. The consensus of opinion is that differences within the voicing dimension for many languages reflect the timing of glottal activity relative to supraglottal articulatory adjustments and the reciprocal effects on air flow and pressure patterns.

Voice onset time (VOT), specified as the difference in time between the release of a complete articulatory constriction and the onset of quasiperodic vocal-fold vibrations, is considered a major cue for differentiation of prevocalic stops along the voicing dimension (Lisker & Abramson, 1964, 1971; Abramson & Lisker, 1965). The traditional phonetic description for the voiced-voiceless distinction in English, based on the presence or absence of vocal-fold vibration, is inadequate (Malecot, 1970; Ladefoged, 1971).

VOT can be derived directly from wide-band spectrograms by measuring the distance between the onset of the burst transient and the first vertical striations representing vocal-fold vibration (Lisker & Abramson, 1964), except under conditions where there is continuous phonation through the closure and the release. In the procedures for specification of VOT, the instant of the burst release is denoted as zero. Negative values, expressed in milliseconds, indicate the time by which voice onset leads the release and positive values indicate the lag time (Lisker & Abramson, 1967).

Spectrographic measurements have shown that voiced stop consonants are distinguished by the onset of laryngeal vibration either preceding or shortly lagging the burst, whereas voiceless stops are characterized by relatively longer lag times in English (Abramson & Lisker, 1967; Lisker & Abramson, 1964, 1967). The frequency distribution for voiceless stops is essentially unimodal (Lisker & Abramson, 1967). The voiced stops /b, d, g/ are associated with VOT values which appear to fall into two discontinuous ranges with modes at about -100 msec and zero (Lisker & Abramson, 1964). Lisker and Abramson (1964) observed three ranges of VOT values employed by English-speaking adults, -125 to -75 msec voicing lead, 0 to +25 msec voicing lag, and +60 to +100 msec voicing lag.

In Kannada, the voiced stops have a VOT range from -89 ms to +19 ms (Savithri, 2002). Sridevi (1990) studied the role of VOT in perceiving voicing contrast in Kannada which has four categories of stops (voiceless unaspirated, voiceless aspirated, voiced unaspirated, and voiced aspirated) and results indicated that VOT can distinguish all the four categories of stops.

Voice onset time varies with place of articulation (Lisker & Abramson, 1964). The VOT values tend to increase for stop consonants which are not characterized by lead time as the point of articulatory constriction changes from labial to apical to velar (Lisker & Abramson, 1964; 1967).

The presence of a hearing loss alters the person’s ability to perceive speech including the perception of VOT. Studies by Holden-Pitt, Hazan, Revoile, Edward, and Droge (1995) have shown that the perceptual crossover boundary is wider in hearing-impaired, while Bennett and Ling (1973) has reported that hearing-impaired children can reliably identify the

VOT contrast. Parady, Dorman, Whaley and Raphael (1981) also noted that hearing-impaired subject’s perception of VOT varied as a function of degree of hearing-impairment. The underlying nature of deficient speech perception by hearing-impaired persons may be better understood through studies of their abilities to distinguish the acoustic cues for the perception of speech. Hearing-impaired listeners appear to base their judgments on very few features.

A major complaint in the hearing-impaired is their difficulty in understanding speech in noisy environments. Most studies that have evaluated speech recognition ability in this population and reported that hearing-impaired listeners consistently perform more poorly than normal hearing listeners in identifying words presented in white noise (Cohen & Keith, 1976; Humes, Schwartz & Bess, 1979), cafeteria or cocktail party noise (Cooper & Cutts, 1971) and speech babble (Aniansson, 1974; Findley & Denenberg, 1977). These results suggest that the speech cues necessary for accurate recognition are perceived differently by hearing impaired listeners than by normal hearing listeners in noise.

Background noise increases difficulties in understanding speech for normal hearing as well as hearing-impaired listeners, in that it reduces the redundancies inherent in speech (Miller, 1974). To obtain adequate communicative efficiency in noise, listeners with sensorineural hearing loss require the signal-to-noise ratio to be improved by +5 to +10 dB (Glassberg & Moore, 1989), and by an additional +3 to +6 dB in rooms with moderate levels of reverberation (Hawkins & Yacullo, 1984).

NEED FOR THE STUDY:

The purpose of this investigation was to determine whether normal-hearing and hearing-impaired listeners perceive VOT boundaries differently in quite and in different SN ratios. Information regarding the perception of hearing impaired in different listening situation would be helpful in planning a remedial plan for them. The information available from the western studies cannot be directly applies to Indian languages. This is because the VOT boundaries are different in Indian language when compared to western languages (Murthy, 1995). Noise interference with VOT perception in normal hearing and the hearing impaired would throw light on our current understanding of the perception of speech by normal hearing individuals and the kind of remediation that is necessary for the hearing impaired.

One reason for adding background noise to test stimuli is to male the test more representative of real-life listening (Schow & Gatehouse, 1990). A speech-in-noise test may be used to identify and demonstrate communicative difficulties. Evaluating speech recognition in quiet may not provide a realistic index of communicative difficulty in everyday situations because they are often characterized by competing noise (Gatehouse & Haggard, 1987). Since conversation often occur in the presence of competing signals, and word recognition performance in noise cannot be predicted from performance in quiet, there is a need to measure speech perception in the presence of noise. Speech perception abilities in the presence of noise enable the clinician to provide hearing impaired individuals or family members with more realistic expectations of unaided and/or aided auditory performance in everyday situations.

Further, variation in the speech perception abilities of hearing impaired individuals can be seen when the task is made more difficult. Thus, by adding noise to speech increases the difficulty of the test, thereby identifying differences among the hearing impaired.

AIM OF THE STUDY:

1. To examine the ability of hearing impaired adults with varying degrees of hearing loss with reference to normals to use VOT for the perception of voiced-voiceless contrasts,
2. To examine the effect of varying signal-to-noise ratios on speech perception of voiced-voiceless contrasts,
3. To determine the interaction of adverse listening conditions and degree of hearing loss on the VOT boundary.

In order to conduct this study, it is essential to know the findings of other researchers, both in the western countries as well as India. This information would provide a basis for comparison. The following section reviews the perception of VOT in normals and hearing-impaired. Perception of speech in the presence of noise is also reviewed.

REVIEW OF LITERATURE

Speech is a form of oral communication in which transformation of information takes place by means of speech waves which are in the form of acoustic energy (Fant, 1960). Speech perception is the process wherein speech is decided and interpreted by the listener. In this process, first the speech signal is analyzed temporally and spectrally at the lower centers. Then the linguistic components are added at the higher centers of the cortex. Thus, when the listener has reconstructed the signal, speech is said to be perceived. Speech sounds are varied and have numerous acoustic cues. It seems that the auditory system depends on some of the acoustic cues of the speech sounds to identify and thus to perceive it (Kiedel, Kallert, Korth, & Humes, 1983, cited in Musiek & Barah, 1986).

The process of speech perception in human beings is of interest and extensive research has been conducted in the recent past to obtain knowledge about the processing of speech signals in the auditory pathway. The result of these researches (Erber, 1972; Byres, 1973; Bennett & Ling, 1973; Johnson, Whaley, & Dorman, 1984) has enhanced the knowledge about the process of speech perception and has provided information about the cues that could be used with the hearing handicapped.

In most of the speech perception studies (Zlatin, 1974; Stevens & Klatt, 1974; Lisker, 1975; Williams, 1976; Summerfield & Haggard, 1977; Parady, Dorman, Whaley & Raphael, 1981), speech sounds are reconstructed from their known spectral and temporal parameters and presented to the listeners for judgment. The parameters of the acoustic signal can be altered individually or in combination to evaluate the effect of their cues on listeners' perception.

Voicing cues have been studies extensively among stop consonants. Voice Onset Time (VOT) is the temporal interval from the release of an initial stop to the onset of glottal pulsing to the closure of the glottis for a following vowel (Lisker & Abramson, 1964, 1967). It is known to play a major role in distinguishing initial voiced and voiceless (or lax or tense) stops in English as well as in a number of other languages. In English, the voiceless stops /p, t, k/ have a positive VOT (with voicing lagging after the stop release) which is greater than or around 30 msec. The voiced stops /b, d, g/ have either a negative VOT (with voicing beginning before the stop release) or a very short positive VOT (Lisker & Abramson, 1964, 1967). Generally the results of these studies indicate that normal hearing adults, presented with synthetic stops, set a voiced-voiceless boundary for /b-p/ between 10 and 30 msec, for /d-t/ between 20 and 40 msec, and for /g-k/ between 20 and 45 msec. Vowel environment does not greatly affect these boundaries but the closer the physical parameters of the synthetic stimuli approximate those of natural speech, the greater the VOT lag has to be before listeners label sounds as voiceless rather than voiced. For example when simulated aspiration is presented during the VOT lag, more lag is required for consonants to be heard as voiceless (Abramson & Lisker, 1965, 1967).

One strategy to assess normal and hearing impaired listeners' sensitivity to small change in VOT is to synthesize signals that differ in small increments of VOT, play these signals to listeners in an identification task and determine the location of the phonetic boundary along the stimulus continuum (Johnson, Whaley, & Dorman, 1984).

VOT as a Perceptual Cue to Voicing in Normals:

Several investigators have studied the ability of normal hearing infants and children to differentiate between synthesized syllables varying along the VOT dimension [Winterkorn, MacNeilage, & Preston, 1967, cited in Bennett & Ling, 1973; Eimas, Siqueland, Jusczyk, & Vigorito, 1971, cited in Bennett & Ling, 1973; Zlatin, 1974). Trehub and Rabinovitch (1972, cited in Bennett & Ling, 1973) also used natural speech stimuli to test infants' ability to discriminate between /da/ and /ta/. The results of theses studies indicate that normal hearing infants, young children and adults have similar VOT boundaries between voiced and voiceless syllables generated synthetically and that infants during their first year can discriminate between voiced and voiceless consonants in natural speech.

Stevens and Klatt (1974) studied speech perception using analysis by synthesis method. Synthetic aspirated and unaspirated stop consonants were used. The perceptual task was to judge whether or not there was an interval of silence between the bursts of noise and onset of buzz. The VOT ranged from 0 to 40 msec and was varied in 5 ms steps. They found that the minimum VOT for 50% recognition of silent interval was 20 ms.

To examine the status of VOT in the perception of word initial voiced and voiceless stops, Zlatin (1974) conducted a study. Synthetic CV syllables with VOT continuum were constructed, ranging from –150 ms to +150 ms, in 10 ms steps at the periphery of each continuum and 5 ms steps in the region of -10 through +60 ms. These tokens were presented to 20 English speaking adults, aged 23 to 40 years. A forced choice procedure was used for

/b-p/, /d-t/ and /g-k/ percept. He concluded that VOT is a primary cue for differentiation of homorganic stop consonants.

The importance of VOT in the perception of voicing was also studied by Lisker (1975). CV syllables were synthesized using stop consonants /k/ and /g/ with the vowel /a/. The temporal parameters were varied in two ways. In the first condition, VOT and F1 onset were varied from 0 to 60 ms in 5 ms steps, the burst duration was 20 ms and the transition duration was 45 ms. The second condition was similar to first condition except F1 was kept constant at 769 Hz for /a/. A forced choice task was used for /k/ and /g/ perception for forty-four normal subjects. Results showed that /g/ and /k/ were clearly divided at about 40 ms of VOT. VOT for /g/ was found to be less than 25 ms and /k/ had greater VOT values.

Darwin and Brady (1975, cited in Brady & Darwin, 1978) used a synthetic VOT continuum ranging from 5 to 55 ms in 5 ms steps, to note its effect on voicing perception. These were presented to the subjects in five blocks, A (15-25 ms), B (15-35 ms), C (25-45 ms) and D (35-55 ms) and one block covering the whole range. These were given for perceptual analysis and the presences of /d/ responses were calculated. Results shown that the location of the voicing boundary in the perception of initial stop consonants was shown to vary according to the range of VOT used in a block of trails, and according to the order in which blocks covering different ranges are presented. Subjects were more willing to perceive as unvoiced, a sound to the long VOT end of a short VOT range than to perceive as voiced a sound to the short VOT end of the corresponding long VOT range.

Perception of voicing by Spanish listeners was studied by Williams (1976), who used synthetically produced syllable initial stops with VOT ranging from – 40 ms to + 40 ms.

Seven out of eight listeners divided the series into voiced and voiceless portion within the perceived region suggesting that prevoicing can be a sufficient voicing cue.

Wood (1976) employed signal detection method to study the phoneme boundary effect. Synthetic stimuli ranging from /ba/ to /pa/ (VOTs from – 50 ms to + 70 ms) were given to 12 normal subjects, aged 18 to 37 years, in a same different discrimination task. Results showed that there was a clear increase in discriminability and a marked shift in response bias from same to different near the voiced-voiceless boundary. This was seen even when VOT were isolated from syllable context so that they were not categorized as phonemes. The results suggest that phoneme boundary effect for VOT is not due exclusively to phonetic categorization but may instead reflect acoustic and auditory properties which are distinct from phonetic processing.

The discriminability of bilabial stop consonants differing in VOT (-100 ms to + 100 ms) as measured in a same-different task, an oddity task and a dual response discrimination-identification task was studied by Carney, Widin and Viemeister (1977). After a moderate amount of training in a same-different task with a fixed standard and with feedback, subjects showed excellent within category discrimination in all three tasks. Discrimination performance continuously improved and well defined category boundaries fell at arbitrary values (-60 to +80 ms) determined by the experimenters.

Diehl (1977) used synthetic CV syllables in an adaptation experiment to evaluate the importance of VOT. Each test syllable had a value of VOT which placed it near the English voiced-voiceless boundary. The investigators found that when the test syllables were preceded by a clear /b/ (VOT = -100 ms) subjects tended to identify them as /p/ (VOT =

+100 ms), the syllables were labeled /b/. This contrast effect occurred even when contextual stimuli were velar and the test stimuli were bilabial suggesting a featural rather than a phonemic basis for the effect.

Elman, Diehl and Buchwald (1977) studied the identification performance of three groups of subjects, monolingual English speaker, monolingual Spanish speakers and English-Spanish bilinguals. Naturally produced /ba/ and /pa/ syllables with VOT ranging from –69 ms to +66 ms were presented for identification. Results indicated that the two monolingual groups differed substantially in their identification performance with the English speakers tending to label most of the stimuli as /ba/ and Spanish speakers tending to label most of them as /pa/. The bilingual listeners' placement of boundaries varied as a function of language set depending on whether they were strong, moderate or weak bilinguals.

Summerfield and Haggard (1977) used synthetic /g-k^h/ stimuli with VOT ranging from 0 to +80 msec to assess perception in six adult subjects in a PEST method experiment. It was found that with increased VOT labels greater number of /k/ percept was reported.

The effects of duration and number of repetitions of an adapting stimulus on the voicing feature scaling of stimuli ranging in VOT before and after adaptation was examined by Ohde (1978). The adapting stimulus was either 5, 25 or 55 ms VOT and the number of repetitions of adaptation trail was 5, 32 or 95. It was found that the 55 ms adaptor was rated as /p/-like and the 5 and 25 ms adaptors were rated as /b/-like. Greater shifts were seen for longer VOT adaptors and greater repetitions. He concluded that the results support a fatigue type model and effects of adaptor repetition support on auditory component of voicing analysis.

The perception of the VOT as a function of age was evaluated by Elliot (1986). Consonant vowel (CV) continuum in which VOT ranged from 0 to 35 ms were presented to 3 groups of subjects: younger children were aged 6 years 2 months through 7 years 9 months (mean 6.8 years) aged, while the older children were aged 8 years 3 months through 11 years (mean 9.6 years) and adults were aged 18 years 1 month through 28 years 6 months (mean 18.6 years). Pairs of CV syllables were used which differed in VOT by 10 and 20 ms. Equal number of catch trails was used, which contained identical CVs. The subjects responded by indication whether the stimuli were same or different. It was found that children displayed poorer discrimination than adults for CV pairs differing by both time intervals. Adults displayed a somewhat greater tendency to respond “same” than children.

VOT as a cue in the perception of voicing has also been studied in different Indian languages. The effect of the temporal parameters in cueing voicing in Kannada and Hindi was assessed by Usha Rani (1989). The stop consonants were studied in intervocalic context. From four meaningful Kannada words- /akka/, /agga/, /appa/, and /abba/, the CV segment was separated and the VOT truncated in steps of 10 ms till it reaches zero and then the series of newly formed tokens were given for perceptual analysis to ten adult native speakers of Kannada and five adult native speakers of Hindi, aged 15 to 35 years. Results indicated that as VOT was truncated no change in percept was reported except for /k/ by Hindi speakers. She concluded that VOT did not cue the perception of voicing in intervocalic position but did cue place of articulation.

Rakesh (1990) studied the effect of the temporal parameters (closure duration, preceding vowel duration, transition duration of the preceding and transition duration of the following vowel) in cueing cluster and voicing features of unaspirated bilabials and velar stops in Malayalam and Telugu. The synthetic test stimuli (VCV) were presented to ten adult native speakers of Malayalam and ten adult native speakers of Telugu, aged 17 to 19 years, for perceptual analysis. The results indicated that the closure duration appeared to be a major cue for the perception of voicing and clustering features of stop consonant while preceding vowel duration, preceding vowel transition duration, and following vowel transition duration were found to be insufficient cues for voicing.

Voicing in Kannada as a cue was investigated by Murthy (1995). Three meaningful Kannada words with three voiced plosives /b/, /d/, and /g/ in the word initial position were selected and the VOT truncated in steps of 3 pitch pulses till lead VOT was 0 and silence was added after the burst in 10 ms steps till the lag VOT was 50 ms. These series of synthetic tokens were given to twenty Kannada speaking normal adult subjects, in the age range of 18 to 35 years, for perceptual analysis. The results indicated the lower limits was around -35 ms, upper limit was around +5 ms, 50% cross over was around -9 ms and boundary width was 34 ms (for voiced stops). The perception changes from voiced stop to unvoiced stop consonant, as the VOT values changes from lead to lag. This study indicated that VOT cued voicing in Kannada. These findings contradicted the results obtained by Usha Rani (1989). The difference in finding could be attributed to the difference in method used. Usha Rani (1989) truncated the VOT in steps of 10 ms till it reaches zero and did not added the silence after the burst. Whereas, Murthy (1995) had added the silence in the synthetic tokens till the lag VOT.

The influence of the method of developing a VOT continuum on perception of VOT boundary was demonstrated by Taitelbaum-Swead, Hildesheimer and Kishon-Rabin (2003). They measured the relative weighting of various acoustic cues in the perception of Hebrew voicing. Stimuli consisted of one pair of meaningful words that differ in the voicing of the initial stop. Four different continua were constructed from the pair of natural stimuli. The first two consisted of the voiced burst combined with the vowel that was truncated from the consonant-vowel combination (where the consonant was voiced or voiceless). The remaining two continua consisted of the voiceless burst combined with the same truncated vowels. For each stimulus, a VOT continuum was created varying from -40 to +40 ms in 10 ms segments. Thirteen adult subjects with normal hearing were tested using a two alternative forced choice labeling procedure. The percent of responses to each stimulus of each VOT continuum (/b-p/) was calculated for each individual and combination. The results show that each acoustic cue contributed to the perception of initial voicing in Hebrew: (1) When the stimulus was constructed from the voiced cues, positive VOT values were needed for the voice/voiceless distinction; (2) when the stimulus was constructed from the voiceless cues, negative VOT values were needed for the voicing distinction; and (3) when the stimulus was constructed from voiced and voiceless cues, intermediate VOT values were needed for the voicing distinction. Thus, depending on whether the VOT continuum was constructed from a voiced or voiceless stop, the VOT boundary shifted. These results provide initial information regarding the relative effect of the acoustic cues in the perception of Hebrew stop voicing.

In summary the review suggest that indeed VOT is used as a major cue for voice-voiceless distinction in western languages as well as Indian languages. The studies revealed that VOT boundary effects are due to acoustic and auditory properties and not just due to phonetic-phonemic processing. The placement of the boundaries also shown to be language dependent. This was more evident in bilinguals. The VOT cue also is differentially used by children and adults. Also depending on the way the VOT continuum has been constructed, the boundary could change. Most studies have constructed the VOT continuum from a voiced speech sound, rather than from a voiceless stop.

Studies have been carried out to evaluate the abilities of hearing-impaired individuals to use VOT as a cue for voicing. These studies have been carried out on individuals hearing varying degree of hearing loss.

VOT as a Perceptual Cue to Voicing in Hearing-Impaired:

Children with sensorineural hearing impairments of moderate to severe degree are known to identify the voicing characteristics of naturally produced stop consonants accurately (Erber, 1972; Byres, 1973). These experiments establish that hearing impaired children can readily identify signals which differ greatly in the acoustic uses that signal voicing. However, because the VOT of contractive phones can differ by as much as 100 ms (e.g. a 50 ms perceived stop vs. a 50 ms devoiced stop). These experiments do not assess whether hearing impaired children are as sensitive as normal hearing children to the acoustics correlates of VOT. The answer to this question is central to understanding the effects of cochlear damage on the processing of the acoustic cues of voicing.

These perceptual effects in normal phoneme decoding were first tested with severely hearing impaired children by Bennett and Ling (1973). In that experiment, ten children with normal hearing and ten children with severe sensorineural hearing loss, aged 8 to 11.5 years, were presented stimuli chosen for different values of VOT from naturally produced /b/-/p/,

/d/-/t/, and /g/-/k/. The outcome was that the children evidenced very poor identification of voicing. Indeed at VOTs of 0 to 20 ms, the children evidenced chance identification, while at 120 ms, only 76% of the responses were voiceless. The conclusion from this study was that children with severe sensorineural hearing loss cannot reliably identify voiced and voiceless stops. This finding differs markedly from the conclusion reached by Erber (1972) and Byres (1973) that severely hearing-impaired children distinguish accurately between voiced and voiceless stops.

Parady, Dorman, Whaley and Raphael (1981) carried out an experiment using a continuum /da-ta/ of 10 synthetic syllables having VOTs of -10, 0, 10, 20, 25, 30, 35, 40, 50, and 60 ms. Both identification and discrimination tasks were used, for groups of ten children with normal hearing sensitivity, eight children with moderately hearing impairment, ten children with severely hearing impairment, and three children with profoundly hearing impairment. They found that the identification and discrimination of stop voicing vs. VOT was normal, with a boundary region between 20 and 40 ms, for listeners with only moderate impairment and 5 of the 10 listeners with severe impairment. The other five showed either a diffuse, lengthened boundary or no boundary effect at all. One profoundly deaf subject had normal characteristics or response to the VOT cue for voicing while another could discriminate well between two stimuli across the boundary but did not correctly assign the longer VOTs to an unvoiced category. Also one profound listener showed good discrimination of VOT which he apparently had never learned to use as identification cue. They concluded that these subjects had the auditory capacity to resolve differences in VOT but could not use this capacity to make phonetic identification. All subjects with a moderate hearing impairment had perception like that of normals. However, those with a higher degree of hearing impairment showed variations in the auditory perceptual abilities.

The finding of Parady, Dorman, Whaley and Raphael (1981) was not replicated in a study by Johnson, Whaley and Dorman (1984). They assessed whether young hearing impaired listeners are as sensitive as normal hearing children to the cues for stop consonant voicing. They presented stimuli from along VOT continua in test with two response alternatives (e.g. /ba-pa/), four alternatives (/ba-pa/, /da-ta/) and six response alternatives (/ba-pa/, /da-ta/, /ga-ka/) to eighteen young normal hearing listeners and twenty-four hearing impaired listeners with mild, moderate, severe and profound hearing impairments, aged 8 to 16 years. The response measures were the location of the phonetic boundaries, the change in boundaries with change in place of articulation, and response variability. They found that the listeners with normal hearing sensitivity and those with mild and moderate hearing impairments did not differ in performance on any response measure. The listeners with severe impairments did not show the expected change in VOT boundary with changes in place of articulation. Moreover, stimulus uncertainty (i.e., the number of possible choices in the response set) affected their response variability. One listener with profound impairment was able to process the cues for voicing in a normal fashion under conditions of minimum stimulus uncertainty. From these results they inferred that the cochlear damage which underlies mild and moderate hearing impairment does not insignificantly alter the auditory representation of VOT. However, the cochlear damager underlying severe impairment, possibility interacting with high signal presentation levels, does alter the auditory representation of VOT.

The influence of voice onset time (VOT) and vowel onset characteristics on the perception of the voicing contrast for initial plosive consonants was examined for hearing-impaired children, and normal-hearing children and adults by Holden-Pitt, Hazan, Revoile, Edward, and Droge (1995). Listeners identified spoken 'DAD'--'TAD' stimuli controlled for VOT and vowel onset characteristics. Only six of the sixteen hearing-impaired children appropriately identified the exemplar DAD and TAD stimuli used as endpoints of VOT continua. For this group of six hearing-impaired children, a longer VOT than for the normal-hearing listeners was required to elicit /t/ rather than /d/ percepts. The VOT region of perceptual cross-over in labeling widened progressively from normal-hearing adults to normal-hearing children to hearing-impaired children. Generally, longer VOTs were required to yield /t/ perception in the context of the DAD vowel than with the TAD vowel. These 'vowel stem' effects on VOT boundary were inconsistent for the hearing-impaired children, and weaker for the normal-hearing children than for the adults. These spoken stimuli produced results for VOT cue use that generally parallel those obtained in studies with synthetic stimuli.

The majority of studies indicated that perception of voicing is altered due to presence of a hearing loss though there are individual variations among subjects. A few studies do say that the voicing can be perceived by the hearing-impaired, these studies have not measured VOT identification (Erber, 1972; Byres, 1973). It has been agreed upon that as degree of loss increases the VOT identification becomes poorer. The degree of loss at which marked difference occur are not agreed by various researchers. From the review, it is evident that no such study has been conducted on hearing impaired individuals speaking Indian languages.

The VOT as a perceptual cue for place of articulation is has been studied by few experimenters. Though it has been studied more as a cue for the perception of voicing, its influence in the perception of place has drawn some interest.

VOT as a Perceptual Cue to Place of Articulation in Normals:

VOT is found to be dependent on the place of articulation. As the tongue moves back for the articulation of stops, VOT becomes larger. This is also true for the perception of voiceless stops (Delattre, Liberman, & Cooper, 1955). For labials, the VOT is 25 ms, for alveolars 35 ms and for velars 40 ms. Later studies have also agreed with this finding. VOT typically increases from labial to apical to velar points of articulation as reported by Lisker and Abramson (1964).

Zlatin (1974) studied both perceptual and productive VOT characteristics of adults. Synthetic syllables with VOT ranging from –150 ms to +150 ms were given for perceptual analysis voicing a forced choice method. Results showed a consistent increase in crossover value as place of articulation moved.

The location of voiced-voiceless boundary as a function of place of articulation was assessed by Miller (1977). He presented synthetic stimuli /ba, pa, da, ta, ga, ka/ with VOT ranging from 0 to +50 ms in an identification task to eighteen normal university students. The findings were similar to that of Lisker and Abramson (1964) i.e. phonetic boundary systematically shifted towards the voiceless end of the series as the place of articulation varied from front to back. Miller concluded that at least for stimuli near the phonetic boundary, the assignment to a voicing value is contingent on place value assigned.

Repp (1977) investigated the dependence of voicing boundaries on place cues by varying F2 and F3 transition onset frequencies of syllable initial stop consonants as well as their VOT. He reported evidence for change in voicing boundary which was tied to the perceived place category. Also a dependence of the place boundary on VOT (labial-alveolar-velar boundaries) converge as VOT increases resulting in a reduction of the size of the alveolar category.

Volaitis and Miller (1992) studied the effect of place of articulation on the perception of voicing. Synthetic tokens /bi/ and /gi/ were given for perceptual analysis to three undergraduate male subjects. Results shown that a change in place of articulation from labial to velar consonants resulted in a shift in the voiced-voiceless category boundary values towards longer VOT values. This effect was seen irrespective of the speaking rate.

Effect of place of articulation on the perception of VOT continua was examined by Nearey and Rochet (1992). Twelve different continua (VOT ranging form –80 to +80 ms in 10 ms steps) were presented to English and French speakers for perceptual analysis. The consonants taken were /b, d, g, p, t, k/. Results indicated that both French and English speakers showed significant effects for place. As place of articulation moved, the voiced-voiceless cross over boundary valued reduced.

It is evident from the studies on normal hearing individuals, that VOT could be a cue to place of articulation. A change in VOT as a function of place was seen in production as well as perception studies. Similar studies on the hearing impaired population are relatively few.

VOT as a Perceptual Cue to Place of Articulation in Normals:

Change in the boundary with place of articulation was assessed by Johnson, Whaley and Dorman (1984). They presented stimuli along a VOT continuum to eighteen young normal hearing listeners and twenty-four hearing impaired listeners with mild, moderate, severe and profound hearing impairments, aged 8 to 16 years. Results shown that the performance of the listeners with severe impairment differed from that of the normals. The VOT boundary fell at progressively longer values when place of articulation changed from labial to alveolar to velar. They also reported that for listeners with moderate hearing impairment the processing of the cue for voicing was unhindered by abnormal processing of place of articulation.

VOT as a cue for the perception of place of articulation in the hearing-impaired has not been given much importance in literature. This is probably because it is not considered a major cue in the perception of place of articulation.

Effect of Signal-to-Noise Ratio (SNR) On Speech Perception:

A major complaint of many hearing-impaired listeners is difficulty understanding speech in noisy environments. Most studies that have evaluated speech recognition ability in this population have confirmed this report. Hearing-impaired listeners consistently perform more poorly than normal hearing listeners in identifying words presented in white noise (Cohen & Keith, 1976; Humes, Schwartz & Bess, 1979), cafeteria or cocktail party noise (Cooper & Cutts, 1971) and speech babble (Aniansson, 1974; Findley & Denenberg, 1977). Further, when normal hearing and hearing-impaired subjects are matched for possible sources of variability on speech recognition performance, such as age and speech recognition in quiet. The hearing-impaired listeners continue to exhibit poorer performance (Aniansson, 1974; Findlay & Denenberg, 1977). These results suggest that the speech cues necessary for accurate recognition are perceived differently by hearing-impaired listeners than by normal hearing listeners in noise.

A direct examination of the specific speech cues that are perceived by listeners entails assessment of consonant phoneme perception. An analysis of this type would reveal which of the speech cues perceived by hearing-impaired listeners are masked by noise and whether hearing-impaired listeners process these speech cues differently from normal hearing listeners in noise (Gordon-Salant, 1985).

Crum (1974, cited in Tyler & Schum, 1995) measured word recognition in normal hearing listeners at signal-to-noise ratios of +12 dB, +6 dB, and 0 dB. Results show that although mean recognition scores were 95% at a signal-to-noise ratio of +12 dB, percent correct scores decline to 80% and 46% at signal-to-noise ratios of +6 dB and 0 dB, respectively.

Background noise increases difficulties in understanding speech for normal hearing as well as hearing-impaired listeners, in that it reduces the redundancies inherent in speech (Miller, 1974). Numerous investigations have shown that the speech recognition performance of hearing impaired listeners is degraded in noise when compared to normal hearing listeners (Dubno, Driks, & Morgan, 1984; Suter, 1985).

Resnick, Dubno, Hoftnung and Levitt (1975) presented nonsense syllable test to hearing impaired listeners in a background of cafeteria noise at +20 dB SNR. The results indicated significant effect of vowel context, consonant position, voicing manner, place and audiometric configuration on perception.

Finitzo-Hieber and Tillman (1978) evaluated monosyllabic word recognition at various signal-to-noise ratios (+12 dB, +6 dB, & 0 dB) and reverberation times (T= 0.0, 0.4, & 1.2 sec). Twelve normal-hearing and twelve children with mild hearing loss, aged 8 to 12 years, served as subjects. Results shown that hearing-impaired subjects' speech recognition scores were poorer under all listening conditions. Mean scores for normal-hearing subjects were 60% at the 0 dB SNR, 80% at the +6 dB SNR, 89% at the +12 dB SNR, and 95% in quiet. For the hearing-impaired subjects, scores were 83 % in quiet, 39% at the 0 dB SNR, 60% at the +6 dB SNR, and 70% at the +12 dB SNR.

Givens and Jacobs-Condit (1981) determined the effect on consonant identification of speech-to-noise ratio. The California Consonant Test (CCT) was given to 20 normal-hearing young adults and 14 patients (mean age 56.1 years) with sloping sensorineural hearing losses. The CCT was given individually at the Most Comfortable Level (MCL) in quiet and at that level in broad-band noise adjusted to yield +20, +10, 0, and -10 dB S/N, consecutively. Mean percent-correct scores for the patients were 50, 44, 40, 38, and 32 respectively, and were 97, 90, 73, 47, and 37 respectively for the controls. Confusion matrices constructed for each of the five noise conditions for each group revealed that at S/N of 10 dB, normal subject began consistent and systematic substitutions in manner and in place of articulation, never in voicing or nasality. This pattern was in general followed by the patients, except that substantial confusions existed also at the two easiest ratios.

Sensorineural hearing loss often produces difficulties in speech recognition over and above the filtering effect, and that these difficulties are particularly evident when the speech signal is disrupted by noise. Levitt (1982, cited in Suter, 1985) listed the suprathreshold distortions that have been associated with speech recognition problems by various researches; distortions of loudness relationship, reduction in frequency selectivity, reduction in sensitivity in intensity change, poor temporal processing, broadened critical band and poor ability to extract signals from noise, greater spread of masking effects, nonlinear distortion components, and reduced linear range of the auditory system. Levitt pointed out that most of the distortions were highly correlated with the amount of hearing loss, and therefore with amount of speech spectrum available to the hearing impaired listener.

Suter (1985) reported that at a signal-to-noise of -6 dB, hearing impaired listeners obtained monosyllabic recognition scores of 27% correct compared to 63% for normal listeners. Crandell and Bess (1986) reported that hearing impaired listeners required higher signal-to-noise ratios than adult normal hearing listeners to achieve equivalent recognition scores. In general, speech perception in normal-hearing adults is not affected until the SNR in the environment decreases below 0 dB. To obtain adequate communicative efficiency in noise, listeners with sensorineural hearing loss require the signal-to-noise ratio to be improved by 5 to 10 dB (Glassberg & Moore, 1989), and by an additional 3 to 6 dB in rooms with moderate levels of reverberation (Hawkins & Yacullo, 1984).

The poor perception of the hearing-impaired, in the presence of noise has been demonstrated in several other studies. Gordon-Salant (1985) determined whether normal hearing and hearing impaired listeners perceive phoneme features differently in noise and also whether phoneme perception changed as a function of SNR. Consonant vowel recognition by ten normal hearing and ten hearing impaired listeners were assessed in quite, 0 dB SNR, +6 dB SNR and +12 dB SNR. Results of the experiment demonstrated that the hearing impaired subjects recognized nonsense syllables more poorly than did the normal hearing subjects in both quite and noise conditions.

In agreement with the earlier studies, Stone and Moore (1992) reported that people with a sensorineural hearing loss often have difficulty understanding speech in background noise at speech-to-noise ratios (0 to +6 dB) for which normally hearing people have little difficulty.

Crandell (1993) examined the speech recognition of children with minimal degree of sensorineural hearing loss at various signal-to-noise ratios (+6, +3, 0, -3, & -6). Speech recognition was assessed with the Bamford-Kowal-Bench (BKB) Standard sentences test presented at a level of 65 dB SPL, while the multitalker babble from the Speech Perception in Noise (SPIN) teat was used as the noise competition. Results suggested that the children with a minimal degree of hearing-impairment performed more poorly across most listening conditions. Performance decrement between the two groups increased as the listening environment became more adverse. At a signal-to-noise ratio of +6 dB, both groups obtained recognition scores of 80%. At a signal-to-noise ration of -6 dB, however, the minimally hearing-impaired group was able to obtain less than 50% correct recognition compared to approximately 75% recognition ability for the normal listeners.

The use of continuous and interrupted noise masks in speech perception experiments is relatively new. However, the paradigm has been successfully used by Phillips, Rappaport and Gulliver (1994) in patients with noise-induced cochlear hearing loss. They found the patients with the cochlear hearing loss showed a significant recognition impairment only for words presented against the interrupted masker, and concluded this was indicative of a temporal resolution deficit.

Beattie, Barr, and Roup (1997) studied the effects of noise on word recognition scores on normal-hearing and hearing-impaired subjects. Fifty-one normal-hearing subjects were tested at 50 dB HL using SNRs of 5, 10, and 15 dB. Thirty subjects with mild-to-moderate sensorineural hearing losses were tested in quiet and in noise at SNRs of 10 dB and 15 dB. Monosyllabic words in a “Multitalker Noise” were selected for testing. Mean scores for the normal-hearing subjects were 45% at the 5 dB SNR, 74% at the 10 dB SNR, and 87% at the 15 dB SNR. For the hearing-impaired subjects, scores were 85% in quiet, 60% at the 15 dB SNR, and 40% at the 10 dB SNR. These results suggested that background noise, which is mildly disruptive for normal hearing subjects can be highly disruptive to hearing-impaired subjects. Moreover, these findings indicate that subjects with mild-to-moderate sensorineural hearing loss require a more favorable SNR than normal listeners to achieve comparable word recognition scores.

From these studies, it appears that noise has a more devastating effect on individual with sensorineural losses than on those who hear normally. Studies evaluating overall word and syllable recognition in noise usually have shown that hearing impaired listeners perform more poorly than normal hearing listeners. The review of literature on the perception of VOT in normal and hearing-impaired individuals shows that there does exist a difference in which this cue is used by these two groups in the perception of voicing. It is generally noted that as the degree of hearing impairment increases, the perceptual boundary of the VOT also alters.

Few studies have evaluated the perception of voicing in subjects with a hearing impairment, in the presence of noise. Variation in the perception of VOT in normal and hearing-impaired individuals has not been studied extensively as a function of place of articulation. Thus, there is a need to study the perception of voicing in subjects with hearing impairment, in the presence of noise as well as in different place of articulation.

METHOD

The study was done with the aim to examine the ability of hearing impaired adults with varying degree of hearing loss to use VOT for the perception of voiced-voiceless contrast, in the presence of different signal-to-noise ratios. The interaction of adverse listening conditions and degree of hearing loss on the VOT boundary was studied. A comparison was made between the perception of voicing in hearing impaired individuals and normal hearing subjects.

Subjects:

Ten mild and ten moderate sensorineural hearing-impaired adults and twenty normal hearing adults, in the age range of 18 to 56 years with a mean age of 36.5 years, served as the subjects. The subjects met the following criteria:

Criteria for the hearing impaired group:

- Subjects had a mild-to-moderate sensorineural hearing loss (Flat audiogram configuration),
- The onset of hearing loss was after 10 years of age,
- They were above the age of 18 years,
- They had no history of middle ear pathology,
- Subjects were able to read Kannada,
- They had clear speech with no misarticulation,
- They had speech identification scores between 75% to 100% on a speech identification test.

Criteria for the normal hearing group:

The subject selection criteria for the normal hearing population was the same as that of the hearing impaired group, except that they had pure tone thresholds within normal limits and a speech identification of 100% in quiet.

Procedure:

Material development:

Consonant vowel (CV) syllables were used as test stimuli. The consonants were voiced unaspirated stops, /b/, /d/ and /g/. Each of these consonants were followed by the vowel /a/. The speech stimuli were recorded by a male speaker, whose mother tongue was Kannada. The recording was done on a Pentium IV computer using a unidirectional microphone kept at a distance of 10 cm form the speaker's mouth. These were digitally recorded on a computer with a sampling frequency of 16 kHz. The recorded material was scaled/normalized using the "Audiolab software" (Voice & Speech systems, Bangalore) so that all tokens were of the same intensity. Three VOT continua /ba-pa/, /da-ta/, and /ga-ka/ were prepared from lead to lag VOT.

Using the "Praat software" (Version 4.2.01), voicing pulses were truncated in steps of 2 pitch pulses, which was approximately 15 ms in duration, until the VOT was completely removed. This point was labeled as having 0 ms VOT. Once the pre-voicing was removed, silence was added after the burst in 10 ms steps till the total duration of silence was equal to the duration of lag VOT for the same token as uttered by the same subject, thus approximating a voiceless plosive. A total of 12 token for /b/, 11 token for /d/, and 10 token for /g/ were synthesized. Table 1, show the original lead VOT and the values for the subsequent synthetic tokens.

Table 1: VOT values (ms) for the original and synthetic tokens

	Tokens	***/ba/***	***/da/***	***/ga/***
1.	Original	-110	-98	-84
2.	Synthetic	-97	-87	-70
3.	”	-80	-67	-57
4.	”	-65	-52	-40
5.	”	-50	-36	-21
6.	”	-32	-18	0
7.	”	-16	0	+10
8.	”	0	+10	+20
9.	”	+10	+20	+30
10.	”	+20	+30	+40
11.	”	+30	+40	
12.	”	+40		

In all there were thirty-three tokens. These tokens were randomized five times to form five different lists. The randomization was done to avoid any order effect of the list. An interstimulus interval of three milliseconds was maintained for obtaining the responses from the subjects.

1. Procedure for Subject Selection:

A preliminary pure tone test was done to find out the hearing threshold of the subjects using Madsen OB922 diagnostic clinical audiometer, calibrated according to ANSI S3.6-1996 standards (cited in Wilber, 2002), with TDH-39 earphones and B-71 bone vibrator. Air-conduction thresholds were obtained between 250 Hz and 8 kHz and bone conduction thresholds were obtained between 250 Hz and 4 kHz. Screening tympanometry and reflex threshold testing was done using GSI 33 impedance audiometer, calibrated according to ANSI S3.39-1987-R, 1996 (cited in Wilber, 2002), to rule out the presence of any middle ear pathology. Speech recognition threshold (SRT) and speech identification (SI) were obtained using the Kannada Spondee Word List, developed in Department of Audiology, AIISH, and the Common Speech discrimination Tests for Indians (Mayadevi, 1974), respectively.

2. Procedure for CV Material Evaluation:

The developed material was played, using the "Audiolab software". The output from the computer was routed to the tape input/auxiliary input of the audiometer (OB922). Prior to the presentation of the stimuli, a 1 kHz calibration tone was played to set the VU-meter defection of the audiometer to '0'. Subjects heard the token through a headphone (TDH-39). The normal hearing individuals received the tokens at 45 dBHL, which is the normal conversation level. The hearing-impaired individuals were tested at 40 dBSL (with reference to their PTA). All the subjects heard all five lists 3 times in the three different listening conditions i.e. one list was presented in quiet, the other two lists were presented in the presence of speech noise at +5 dB and +10 dB SNR in the ear ipsilateral to the stimulus presentation.

Each subject listened to all the stimuli. The subjects were given a response sheet (Appendix- A) and were asked to tick (√) the speech sounds they heard, from a multiple forced choice given to them.

Analysis:

The data thus obtained was tabulated and percentage response for the stimulus was calculated by the following formula.

$$\text{Percentage Response} = \frac{\text{Obtained number of responses}}{\text{Total number of responses}} \times 100$$

For, e.g., if the total or expected number of response for a stimulus was 5 and the obtained number of response was 4 then percent response was 4/5 X 100 = 80%.

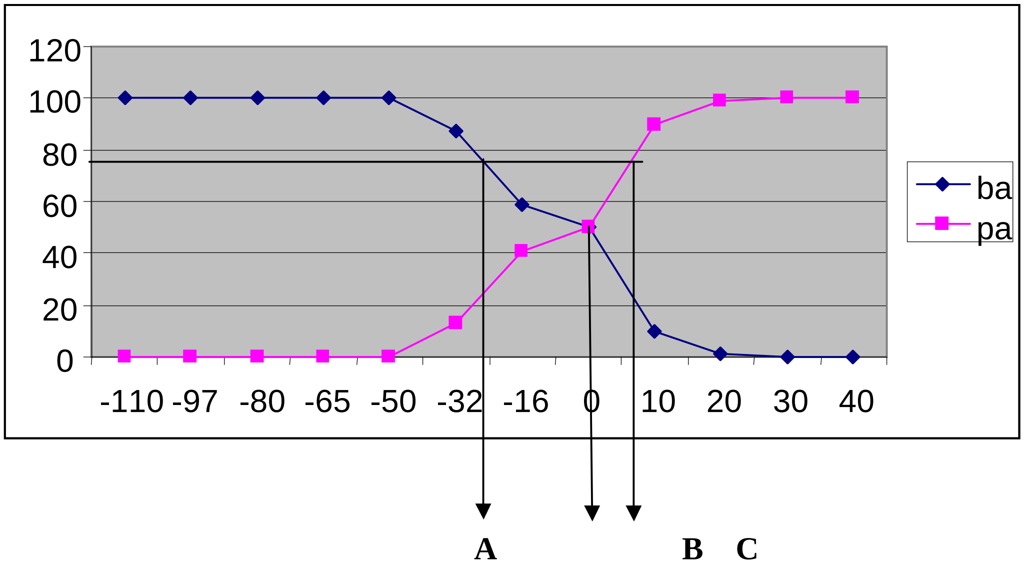
The percent responses for voiced and voiceless plosives were tabulated for each of the test stimulus on the basis of which the identification function for each plosive was plotted.

Four measurements were noted from the identification function (modified from Lisker & Abramson, 1964) obtained for VOT, from each subjects.

I. **Lower limit of the phoneme boundary width:** It was that point along the VOT continuum where an individual identified voiced stop 75% of the time (In figure 1: Point A).

II. **50% Cross over:** It was that point, which was the actual or interpolated point about the VOT continuum for which 50% of the subject's response corresponded to the voicing category (In figure 1: Point B).

Figure 1: The lower limit, upper limit, 50% crossover and phoneme boundary width



III. **Upper limit of Phoneme boundary width:** It was defined as the corresponding point for the identification of voiceless cognate, 75% of the time (In figure 1: Point C).

IV. **Phoneme boundary width (in ms) between voicing category:** It was defined as the arc boundary crossover point along the VOT continuum and was determined by subtracting the lower limit from the upper limit (In figure 1: Point C-A).

The responses obtained were subjected to statistical analysis. The SPSS (version 12.0) was used for this purpose.

These measurements were used to analyze the effect of VOT on the perception of stop consonants in Kannada speaking normal subjects and hearing impaired subjects.

RESULTS

This study was done to assess the perception of VOT as a voicing cue in the perception of stops, in Kannada speaking adults. Three main issues are addressed: The variations in perception as a function of hearing threshold; the effect of noise on the perception of voicing contrast in normal hearing versus hearing-impaired adults and; the effect of phoneme contrast in the perception of voicing in normal hearing versus hearing-impaired adults in different listening condition (quiet, +10 dB SNR, & +5 dB SNR).

In order to study the four measures of identification functions of the bilabials /ba-pa/, alveolar /da-ta/, and velar /ga-ka/ stop cognates were plotted for each subject. These measurements were (a) lower limit of the phoneme boundary, (b) VOT 50% crossover, (c) upper limit of phoneme boundary and (d) phoneme boundary width between voicing contrast.

The mean and standard deviation was calculated for each of the above measures. In addition, an analysis of variance was used to see the interacting effect of varying degree of hearing loss and effect of noise, for each of the four measurements. A Tukey's post-hoc test for means was performed wherever necessary.

As mentioned earlier (Table 1), the synthetic stop continuum /ba-pa/, /da-ta/ and /ga-ka/ had a VOT ranged from -110 to +40 ms, -98 to +40 ms and -84 to +40 ms, respectively. The negative values represented a lead VOT and the positive values represented a lag VOT. The point where the pre-voicing ended was labeled as 0 ms VOT.

(a) The lower limit of phoneme boundary:

The lower limit of phoneme boundary was the point along the VOT continuum where an individual identified voiced stop 75% of the time. The mean and standard deviation values of the lower limit of the phoneme boundary for each group on the three continua are presented in Table 2. The effect of hearing thresholds, different signal-to-noise ratio (SNR), and phoneme contrast on the lower limit of phoneme is discussed in the following section.

Table 2: Mean and SD of lower limit of the phoneme boundary (in ms) on three VOT continua for each listener group

Continuum	**Listener group**	**Quiet**		**+10 dB SNR**		**+5 dB SNR**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
/ba-pa/	Normal	-22.9	2.3	-25.5	3.5	-27.0	3.2
	Mild	-41.8	4.7	-46.6	5.6	-48.5	5.7
	Moderate	-63.5	5.6	-68.4	5.4	-71.4	5.8
/da-ta/	Normal	-31.8	2.4	-35.5	2.3	-38.9	1.7
	Mild	-36.5	3.1	-40.2	4.4	-46.5	7.9
	Moderate	-55.3	7.2	-59.7	6.0	-63.2	5.4
/ga-ka/	Normal	-34.3	2.6	-40.1	3.3	-40.0	1.7
	Mild	-43.6	4.4	-45.8	5.4	-49.8	5.2
	Moderate	-60.6	4.1	-64.6	4.3	-66.8	5.5

(i) Effect of hearing thresholds:

It was noted that, in the quiet condition, subjects with normal hearing thresholds obtained a larger mean value for the lower limit of the phoneme boundary. As the degree of hearing-impairment became higher, the value of the lower boundary also decreased. This trend was observed for all three phoneme contrast (Table 2).

An analysis of variance for repeated measures revealed a stastically significant difference among listener groups [F (2,333) = 33.073, p < 0.000]. Tukey's post-hoc test for means revealed that all the listener groups had significant mean differences from each other ($p < 0.01$). These findings were observed for all the three phoneme contrasts.

(ii) Effect of different SNRs:

Effect of noise on the perception of the lower boundary in the three listener groups was studied. Table 2 shows the mean and SD for the three listening condition and the three phoneme contrast. It was noted that all the three listener groups had lower mean values of the lower limit in the quiet condition followed by the +10 dB SNR and +5 dB SNR conditions.

An analysis of variance for repeated measures revealed a stastically significant difference across the lower limits of the phoneme contrasts (Table 3).

Table 3: Level of significance across listening condition for the lower limits of the phoneme contrasts

Listening condition	**df**	**F**	**Level of significance**
Quiet	2	283.02	.000**
+10 dB SNR	2	232.69	.000**
+5 dB SNR	2	271.42	.000**

(** Significance at 0.001 level)

Tukey's post-hoc test for means revealed that there was significant mean difference between the three listener groups ($p < 0.01$).

(iii) Effect of phoneme contrast:

The present data indicated that the lower limits of the phoneme boundary was in the lead VOT range and the lower limit was longer for the bilabials (/ba-pa/) followed by alveolar (/da-ta/) and velar (/ga-ka/) in the subjects (Table 2). The lower limit decreased as the place of articulation moved back in the oral cavity. The mean value of the lower limit was found to be larger in the quiet condition followed by the +10 dB SNR and the +5 dB SNR conditions. Table 4 shows the significance difference between the listeners indicating that they were highly significant.

Table 4: Level of significance of the lower limits for the phoneme contrasts

Continuum	df	F	Level of significance
/ba-pa/	2	911.56	.000**
/da-ta/	2	200.90	.000**
/ga-ka/	2	308.03	.000**

(** Significance at 0.001 level)

(b) VOT 50% Crossover:

The 50% crossover was that point, which was the actual or interpolated point about the VOT continuum for which 50% of the subject's response corresponded to the voicing category. The mean and standard deviation values of the lower limit of the phoneme boundary for each groups for the three continua are presented in Table 5. As in the previous section the effect of the hearing threshold, SNRs and phoneme contrasts on the 50% boundary was determined.

Table 5: Mean and SD of VOT 50% crossover (in ms) for three VOT continua for each listener group

Continuum	Listener group	Quiet		+10 dB SNR		+5 dB SNR	
		Mean	SD	Mean	SD	Mean	SD
/ba-pa/	Normal	-4.9	4.2	-5.1	2.9	-6.6	4.6
	Mild	-11.8	4.2	-13.0	4.0	-16.2	4.8
	Moderate	-16.6	4.7	-18.8	4.2	-20.5	6.4
/da-ta/	Normal	-15.6	2.9	-16.5	2.7	-18.8	2.7
	Mild	-17.9	3.6	-18.7	3.0	-20.2	3.9
	Moderate	-20.8	4.9	-22.6	5.7	-24.2	6.0
/ga-ka/	Normal	-7.3	3.9	-8.8	2.8	-9.1	2.7
	Mild	-12.6	3.6	-15.3	4.3	-17.7	4.2
	Moderate	-18.9	3.5	-20.5	5.3	-22.1	4.9

(i) Effect of hearing thresholds:

The 50% crossover for the voiced stop to voiceless stop occurred in the lead VOT range for all the three listener groups. In the hearing-impaired groups, the shift occurred earlier in the VOT continuum. This shift occurred later in the continuum for the normal hearing group. A similar trend was observed for the other two VOT continuum /ga-ka/ and /ba-pa/ also (Table 5).

An analysis of variance for repeated measures indicated a stastically significant difference among listener groups [F (2,333) = 46.189, $p < 0.000$]. Tukey's post-hoc test for means revealed a significant mean difference between the listener groups ($p < 0.01$).

(ii) Effect of different SNRs:

Effect of noise on the perception of 50% crossover was seen in the entire three listener groups. It was noted that all the three listener groups obtained a lower mean value for the 50% crossover in the quiet condition followed by the +10 dB SNR and +5 dB SNR condition (Table 5).

A statistically significant difference was found across the three SNRs. This result was obtained using an analysis of variance for repeated measures (Table 6).

Table 6: Level of significance across listening condition for the 50% crossover of the phoneme contrasts

Listening condition	**df**	**F**	**Level of significance**
Quiet	2	43.39	.000**
+10 dB SNR	2	40.51	.000**
+5 dB SNR	2	30.73	.000**

(** Significance at 0.001 level)

These responses were similar for all the phoneme contrasts. Tukey's post-hoc test for means indicated that the normal hearing group had a significant mean difference from the mild as well as moderate hearing-impaired groups ($p < 0.01$). Likewise, the mild and moderate hearing-impaired groups were significantly different from each other.

(iii) Effect of phoneme contrast:

From the Table 5, it is evident that the 50% crossover occurred in the lead VOT range for all the three listener groups across the three voicing contrasts. The shift from voiced to voiceless occurred earlier for alveolars /da-ta/ followed by velars /ga-ka/ and bilabials /ba-pa/ continuum. The mean value of 50% crossover was significantly different among the three voicing contrasts (Table 7).

Table 7: Level of significance of the 50% crossover for the phoneme contrasts

Continuum	**df**	**F**	**Level of significance**
/ba-pa/	2	245.87	.000**
/da-ta/	2	5.99	.000**
/ga-ka/	2	60.23	.000**

(** Significance at 0.001 level)

(c) The upper limit of phoneme boundary:

The upper limit of phoneme boundary was defined as the corresponding point for the identification of voiceless cognate, 75% of the time. For each of the phoneme contrasts used in the present study, the mean and standard deviation of the upper phoneme boundary limits was calculated (Table 8).

Table 8: Mean and SD of upper limit of the phoneme boundary (in ms) on three VOT continua for each listener group

Continuum	**Listener group**	**Quiet**		**+10 dB SNR**		**+5 dB SNR**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
/ba-pa/	Normal	7.4	1.1	7.2	1.4	6.5	2.1
	Mild	6.6	2.3	6.3	2.1	6.0	3.9
	Moderate	5.3	8.9	4.2	6.5	4.5	9.7
/da-ta/	Normal	5.8	2.5	5.4	1.8	5.5	2.1
	Mild	4.7	3.9	4.8	4.2	6.0	5.5
	Moderate	3.3	2.4	3.1	4.3	3.6	4.5
/ga-ka/	Normal	7.8	1.4	7.5	1.7	6.9	1.7
	Mild	4.7	3.4	3.7	3.5	4.4	4.4
	Moderate	4.2	4.6	3.3	3.7	2.5	5.4

(i) Effect of hearing thresholds:

The upper limit of the phoneme boundary was in the lag VOT range for all the three phoneme contrasts. This was observed across all the three listener groups. The mean value for the upper limit was larger for the normal group followed by the mild and moderate hearing-impaired group. This trend was seen across all the three phoneme contrasts and across listening conditions (Table 8).

This difference was found to be stastically significant based on an analysis of variance for repeated measures [F (2,333) = 31.518, $p < 0.000$]. Tukey's post-hoc test for means revealed that the performance of the normal and the mild hearing-impaired group were not stastically significant ($p > 0.05$). However, the normal and the mild group were significantly different from the moderate group ($p < 0.01$). This is unlike the results found for the lower limits of the phoneme boundary and 50% crossover.

(ii) Effect of different SNRs:

The mean value of the upper limit of the phoneme boundary varied depending upon the SNRs. The mean value of the upper limit gradually increased from the quiet condition to +10 dB SNR and +5 dB SNR conditions (Table 8).

An analysis of variance for repeated measures revealed a significance difference across the three listening conditions (Table 9).

Table 9: Level of significance across listening condition of the upper limit of the phoneme boundary

Listening condition	df	F	Level of significance
Quiet	2	7.06	.001**
+10 dB SNR	2	6.63	.002**
+5 dB SNR	2	3.58	.031*

(** Significance at 0.01 level; * Significance at 0.05 level)

When the performance of listener groups was compared using Tukey's post-hoc test for means, it was found that normal and mild hearing-impaired groups performed similarly in the quiet condition. They were significantly different from the moderate hearing-impaired group ($p < 0.01$). However, in the presence of noise, both +10 dB SNR and +5 dB SNR, only the normal subjects performance was significantly different from the moderate hearing-impaired group ($p > 0.05$).

(iii) Effect of phoneme contrast:

From the Table 8, it is clearly evident that the upper limit of the phoneme boundary was low for the alveolars /da-ta/ continua followed by the bilabials /ba-pa/ and the velar /ga-ka/ continuum. The mean value of upper limit was higher in the presence of noise compared to quiet condition. This was seen for all the three phoneme contrasts.

An analysis of variance for repeated measures showed a significant difference between the upper limit of the three phoneme contrasts (Table 10).

Table 10: Level of significance of the upper limits of the phoneme contrasts

Continuum	df	F	Level of significance
/ba-pa/	2	131.07	.000**
/da-ta/	2	22.01	.000**
/ga-ka/	2	5.38	.000**

(** Significance at 0.001 level)

(d) Phoneme boundary width between voicing category:

Phoneme boundary width was defined as the arc boundary crossover point along the VOT continuum and was determined by subtracting the lower limit from the upper limit. The mean and standard deviation of the phoneme boundary width was calculated for each of the continua (Table 11).

Table 11: Mean and SD of phoneme boundary width (in ms) of the three VOT continua for each listener group

Continuum	Listener group	Quiet		+10 dB SNR		+5 dB SNR	
		Mean	SD	Mean	SD	Mean	SD
/ba-pa/	Normal	30.9	3.3	33.6	3.1	34.8	2.7
	Mild	46.9	5.3	53.4	6.1	54.9	6.8
	Moderate	68.8	4.3	73.2	5.5	75.9	5.8
/da-ta/	Normal	38.0	1.9	40.5	3.0	45.7	1.2
	Mild	41.2	5.1	45.0	6.0	52.5	6.2
	Moderate	58.6	5.8	62.8	6.5	67.2	7.0
/ga-ka/	Normal	41.9	1.9	45.8	3.6	45.8	2.2
	Mild	48.6	2.5	50.3	4.5	55.0	4.0
	Moderate	68.1	5.2	71.6	5.8	74.6	6.9

(i) Effect of hearing thresholds:

Differences in the perceptual performance among the three listener groups were clearly evident in the analysis of phoneme boundary width. The phoneme boundary width was longer for the moderate hearing-impaired group and lesser for the mild hearing-impaired group and least for the normal group (Table 11). When all the three boundary widths were averaged for the quiet condition the values were 36.9 ms, 45.5 ms and 65.2 ms for the normal, mild and moderate hearing-impaired groups respectively.

An analysis of variance for repeated measures revealed a stastically significant difference among the three listener groups [F (2,333) = 21.008, $p < 0.000$]. Tukey's post-hoc test for means revealed that there was a significant mean difference between the three listener groups i.e. normal, mild and moderate hearing-impaired groups ($p < 0.01$).

(ii) Effect of different SNRs:

Noise was seen to affect the perception of boundary width in all the three listening conditions. It was observed that boundary width was lesser in the quiet condition and was higher at the +5 dB SNR and intermediate at the +10 dB SNR conditions. This was observed in all the three listener groups (Table 11).

An analysis of variance for repeated measures reveled that boundary width was significantly different across the three listening conditions (Table 12).

Table 12: Level of significance of phoneme boundary width across listening conditions

Listening condition	df	F	Level of Significance
Quiet	2	264.03	.000**
+10 dB SNR	2	233.44	.000**
+5 dB SNR	2	321.85	.000**

(** Significance at 0.001 level)

Tukey's post-hoc test for means indicated that there was a significant difference among the listener groups ($p < 0.01$).

(iii) Effect of phoneme contrast:

The boundary width was significantly different when the phoneme contrasts were considered. This was determined using an analysis of variance for repeated measures (Table 13). The results indicated that the boundary width was more for velars (/ga-ka/) followed by alveolars (/da-ta/) and bilabials (/ba-pa). A similar pattern was seen across different listening conditions for all the three listener groups (Table 11).

Table 13: Level of significance of the boundary width for the phoneme contrasts

Continuum	df	F	Level of Significance
/ba-pa/	2	608.84	.000**
/da-ta/	2	194.36	.000**
/ga-ka/	2	340.02	.000**

(** Significance at 0.001 level)

To summarize, the results indicated the following:

a. *Effect of hearing thresholds:*

- Over all it was seen that the normal group perceived voicing contrast better than mild and moderate hearing-impaired groups. Perception of voiced stop changed to voiceless stop, as the VOT values changed from the lead to the lag VOT. This trend was seen in all the listeners groups (normal, mild and moderate hearing-impaired) across different listening conditions (quiet, +10 dB SNR and +5 dB SNR) for all the three phoneme contrasts (/ba-pa/, /da-ta/ and /ga-ka/).
- Significant differences were observed between the listener groups across the lower limit of phoneme boundary 50% crossover point and boundary width between voicing category.
- No significant difference was seen between the mild hearing-impaired and the normal group, when the upper limits of the phoneme boundary were considered. However, both listener groups were significantly different from the moderate hearing-impaired group.
- The phoneme boundary width was significantly longer for both the hearing-impaired groups compared to the normal group.

b. *Effect of different SNRs:*

- Effect of noise was seen over all the listener groups. From the results, it was clearly evident that the entire listener groups perceived voicing contrast differently in different listening conditions.

- The mean values for all the four identification measures significantly differed for different listening conditions (quiet, +10 dB SNR and +5 dB SNR).
- The noise was less disruptive for normal listeners, but showed significant effect over perception of voicing in the hearing-impaired listeners. Significantly larger boundary widths were seen in the presence noise (+10 dB and +5 dB) for all the listeners when compared to the quiet condition.

c. *Effect of phoneme contrast:*

- In all the listener groups the means for the lower limits increased from bilabials to alveolar to velars.
- The mean value for upper limit of the phoneme boundary was in the lag VOT region for all the listeners in all the three listening conditions. It was low for the alveolar followed by bilabials and velar.
- The 50% crossover point occurred in the lead VOT range of the voicing continuum for all the three stops and it occurred earlier for alveolar followed by velar and bilabial.
- The phoneme boundary width increased from the bilabial to the alveolar to the velar, significantly in all the listening group.

DISCUSSION

From the responses of the three listener groups, the four identification measures were calculated i.e. Lower limit of the phoneme boundary width, 50% Cross over, Upper limit of Phoneme boundary width and Phoneme boundary width. These have been discussed in terms of (a) Effect of hearing thresholds, (b) Effect of different SNRs, and (c) Effect of phoneme contrasts.

(a) Effect of hearing threshold on the perception of voicing:

Overall it was noticed that as the hearing threshold increased, the subjects required longer temporal cues in order to perceive a voiced-voiceless contrast. For all but one measure of identification function, the subjects with normal hearing, mild and moderate hearing-impaired had significantly different perception. For the upper limit of phoneme boundary, normal and mild hearing-impaired subjects performed similarly. Probably, the amount of temporal information received by the mild hearing-impaired group to perceive the upper boundary was adequate to overcome their temporal processing problem. However, it was probably not enough to enable the moderate hearing-impaired individuals overcome their temporal perception problem. The fact that the boundary for all identification shifted more with an increase in hearing threshold, reveals that temporal processing becomes more difficult with increase in hearing threshold.

Similar shift in VOT boundary location have been reported by Parady, Dorman, Whaley and Raphael (1981) and Johnson, Whaley and Dorman (1984), in groups of hearing-impaired individuals. They too observed that with increase in degree of hearing impairment the VOT boundary shifted.

The poor temporal processing in the hearing-impaired group can be accounted for due to a cochlear damage. This has been documented by Levitt (1982, Cited in Suter, 1985).

Moore (1998) also agreed that gap detection and the rate of decay of forward masking both show deterious effects of cochlear hearing loss when the normal and impaired ears are compared at equal SPLs. At equal SLs the discrepancy between normal and impaired hearing is less. Unfortunately, people with cochlear hearing loss usually listen at low SLs, since loudness recruitment makes it impossible to present sound at high SLs without discomfort occurring. Hence cochlear hearing loss leads to poor temporal resolution then normals.

Poor temporal resolutions have been reported in hearing-impaired individuals not only for speech signals, but also for non speech signals. Psychophysical evidence indicates that trained normal hearing observes can discriminate fluctuation in a waveform that occurs in the time intervals as brief as 2-3 ms. Irwin and Suzanne (1982) reported that some listeners with sensorineural hearing impairment have reduced temporal resolving capacity and elevated gap thresholds. The gap thresholds of the hearing-impaired subjects are significantly greater that those of the normal hearing subjects.

Thus, the poor VOT perception seen in the hearing-impaired group can be attributed to the presence of a cochlear damage, which results in a poor perception of voiced-voiceless contrast (Reed, 1975; Bilger & Wang, 1976; Parady, Dorman, Whaley, & Raphael, 1981).

(b) Effect of SNRs on the perception of voicing:

The results of the present study demonstrated that the hearing-impaired subjects recognized voicing with greater difficulty than the normal hearing subjects, both in quiet and adverse listening conditions i.e. at +10 dB SNR and +5 dB SNR. All the three listeners group exhibited a reduction in mean values in the noisy condition.

Evidently the presence of noise caused confusion in perception due to the masking effect of noise. The adverse effect of noise has been reported by Miller (1974). He noted that background noise increases difficulties in understanding speech for normal hearing as well as hearing-impaired listeners by reducing the redundancies inherent in speech. Also, the presence of noise makes the perception of speech cues difficult for hearing-impaired listeners. Gordon-Salant (1985) reported that hearing-impaired process these speech cues differently from normal hearing listeners in noise.

The decreased mean scores of the identification function in the presence of noise is in agreement with the findings of other researcher (Crum, 1974; Finitzo-Hieber & Tillman, 1978; Dubno, Driks, & Morgan, 1984; Suter, 1985; Gordon-Salant, 1985; Stone & Moore, 1992; Crandell, 1993; Beattie, Barr & Roup, 1997). These studies reported that background noise, which is mildly disruptive for normal hearing listeners, can be highly disruptive for hearing-impaired subjects. Subjects with mild-to-moderate sensorineural hearing loss require a more favorable SNR than normal listeners to achieve comparable speech recognition scores (Beattie, Barr & Roup, 1997).

Based on the findings of the present study and that of earlier studies, it is recommended that noise levels should be reduced to enable the hearing-impaired to perceive voice-voiceless contrasts. The present study indicates that a SNR of +10 dB is not acceptable even for individual with a mild hearing impairment.

(c) Effect of phoneme contrast on the perception of voicing:

Results obtained from the three groups of listener revealed that VOT cues voicing in Kannada. All the listeners perceived a long lead VOTs as a voiced stop and a short lead and lag VOTs as voiceless stops. Similar findings that, VOT cues voicing, has been reported in past by Lisker and Abramson, 1964; Zlatin, 1974, Lisker, 1975; Diehl, 1977, Elliot, 1986 and Murty, 1995.

The finding of the present study contradicts the findings of Usha Rani (1989) and Rakesh (1990), who did not find VOT to cue voicing contrast in Indian languages. In the former study Hindi and Kannada were researched while in the later study Malayalam and Telugu were investigated. This difference may be on account of material used for the studies. They evaluated the effect of VOT on perception of voicing in intervocalic stop consonant. However, in the present study, the stop voicing was evaluated in the initial position. The cues for voicing perception changes depending on whether the stop is in the initial, medial or final position (Zlatin, 1974; Williams, 1976; Darwin & Brady, 1975, cited in Brady & Darwin, 1978; Usha Rani, 1989; Murthy, 1995). Further, they manipulated the closure duration where as in the present study VOT was manipulated.

In the present study results shown that VOT values typically increased from labial to alveolar to velar place of articulation i.e. as the tongue moved back for the articulation of stops, VOT became larger. These values were consistent across all the three listeners group in the three listening conditions, which shows that VOT can be a cue for place of articulation. These results are in agreement with other research findings (Delattre, Liberman & Copper, 1955; Lisker & Abramson, 1964; Zlatin, 1974; Miller, 1977 and Repp, 1977). Similar finding has been reported by Johnson, Whaley and Dorman (1984) in hearing-impaired individuals, where the VOT boundary fell at progressively longer values when place of articulation changed from labial to alveolar to velar.

Thus, the findings of the present study indicates that VOT is used as a cue not only for the perception of voiced-voiceless contrast but also as a cue for place of articulation. Whether such results would be seen in other Indian languages needs to be investigated further.

SUMMARY AND CONCLUSION

Voice onset time (VOT), specified as the difference in time between the release of a complete articulatory constriction and the onset of quasiperodic vocal-fold vibrations, is considered a major cue for differentiation of prevocalic stops along the voicing dimension (Lisker & Abramson, 1964, 1971; Abramson & Lisker, 1965). It is known to play a major role in distinguishing initial voiced and voiceless (or lax or tense) stops in English as well as in a number of other languages. VOT can distinguish all the four categories of stops (voiceless unaspirated, voiceless aspirated, voiced unaspirated, and voiced aspirated) in Kannada (Sridevi, 1990).

The presence of a hearing loss alters the person's ability to perceive speech including the perception of VOT. A major complaint in the hearing-impaired is their difficulty in understanding speech in noisy environments. The present study was designed to determine whether normal-hearing and hearing-impaired listeners perceive VOT boundaries differently in quite and at different SNRs (+10 dB & +5 dB) and to determine the interaction of adverse listening conditions and degree of hearing loss on the VOT boundary.

Ten mild and ten moderate sensorineural hearing-impaired adults and twenty normal hearing adults served as the subjects. The voiced unaspirated stops consonants /b/, /d/ and /g/ followed by the vowel /a/ as CV syllable were used as test stimuli. The speech stimuli were digitally recorded on a computer by a Kannada speaking male speaker. Synthetic tokens were created using "Praat software" (Version 4.2.01) by truncating the pitch pulses in steps of two pulses and adding silence after the burst in 10 ms steps once the pre-voicing was removed. In all there were thirty-three tokens. These tokens were randomized five times to form five different lists. All the subjects heard all five lists 3 times in the three different listening conditions i.e. one list was presented in quiet, the other two lists were presented in the presence of speech noise at +5 dB and +10 dB SNR in the ear ipsilateral to the stimulus presentation. A multiple forced choice method was used to obtain responses. Percentage responses for the voiced and voiceless plosives were tabulated for each of the stimulus and identification function for each plosive was plotted for each subjects. Four measurements were noted from the identification function i.e. Lower limit of the phoneme boundary width, 50% Cross over, Upper limit of Phoneme boundary width and Phoneme boundary width. An analysis of variance and Tukey's post-hoc test was performed to know the significance difference in the responses of the hearing-impaired listeners and normal listeners across different SNRs.

The results of the study revealed that normal group perceived voicing contrast better than mild and moderate hearing-impaired groups. Perception of voiced stop changed to voiceless stop, as the VOT values changed from a lead to a lag VOT. This trend was seen in all the listeners groups (normal, mild and moderate hearing-impaired), across different listening conditions (quiet, +10 dB SNR and +5 dB SNR) for all the three phoneme contrasts (/ba-pa/, /da-ta/ and /ga-ka/).

Hearing thresholds resulted in a significant difference in the perception of the lower limit of phoneme boundary, 50% crossover point and boundary width. However, the perception of upper limits of the phoneme boundary was not significantly different between the mild hearing-impaired and the normal hearing groups. Both these listener groups were however, significantly different from the moderate hearing-impaired group. The phoneme boundary width was significantly longer for both the hearing-impaired groups compared to the normal group.

Effect of noise was seen in all the listener groups and it was clearly evident that the entire listener group perceived voicing contrast differently in different listening conditions. The mean values for all the four identification measurements varied from the quiet condition to the +10 dB SNR and +5 dB SNR. A significant larger boundary width was seen in the presence noise (+10 dB and +5 dB) condition for all the listeners, compared to the quiet condition.

It was observed that the there was a significant difference between phoneme contrast for the four measures of identification that were investigated. This shows that the subjects, both normal and hearing-impaired used VOT as a cue for place of articulation, also.

Effect of phoneme contrast was observed as all the listener groups had longer mean for lower limits for bilabial followed by alveolar and velar, irrespective of hearing impairment. The upper limit of the phoneme boundary was in the lag VOT region for all the listeners and it was low for the alveolar followed by velar and bilabial. The 50% crossover point occurred in the lead VOT range and it occurred earlier for alveolar followed by velar and bilabial. The phoneme boundary width increased from the bilabial to the alveolar to the velar. And it was significantly larger for the hearing-impaired groups compared to normal group.

In conclusion, VOT serves as a cue for voicing in Kannada not only for normal hearing listeners but also for hearing-impaired listeners irrespective of adverse listening conditions such as presence of background noise. VOT boundary varies with respect to the hearing threshold level as well as the level of the background noise.

Implication:

The implications of the study are as follows:

The results that the hearing-impaired require longer VOT boundaries to perceive a voice-voiceless contrast could be used in an auditory training program. An auditory training program, using synthetic speech, could be constructed. Initially, the hearing-impaired individual could be taught to perceive between voiced-voiceless contrasts with large VOT differences. Gradually the VOT difference between the voiced-voiceless contrasts can be reduced to approximate the boundary width used by normal hearing individuals. A similar activity can be used to train the hearing-impaired to perceive place of articulation also.

Information on the effect of noise in the perception of the hearing-impaired could be utilized during therapy as well as in a real life situation. Since the hearing-impaired subjects had difficulty in perceiving even with a +10 dB SNR, it is recommended that a therapy program be started with a large SNR.

A similar study could be conducted on individual having a different degree of hearing impairment, types of hearing loss or audiogram configuration.

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APPENDIX – A

Response Sheet

Name: **Age/Sex:** **Comment:**

	ba	***pa***	***da***	***ta***	***ga***	***ka***
1	§	¥À	zÀ	vÀ	UÀ	PÀ
2	§	¥À	zÀ	vÀ	UÀ	PÀ
3	§	¥À	zÀ	vÀ	UÀ	PÀ
4	§	¥À	zÀ	vÀ	UÀ	PÀ
5	§	¥À	zÀ	vÀ	UÀ	PÀ
6	§	¥À	zÀ	vÀ	UÀ	PÀ
7	§	¥À	zÀ	vÀ	UÀ	PÀ
8	§	¥À	zÀ	vÀ	UÀ	PÀ
9	§	¥À	zÀ	vÀ	UÀ	PÀ
10	§	¥À	zÀ	vÀ	UÀ	PÀ
11	§	¥À	zÀ	vÀ	UÀ	PÀ
12	§	¥À	zÀ	vÀ	UÀ	PÀ
13	§	¥À	zÀ	vÀ	UÀ	PÀ
14	§	¥À	zÀ	vÀ	UÀ	PÀ
15	§	¥À	zÀ	vÀ	UÀ	PÀ
16	§	¥À	zÀ	vÀ	UÀ	PÀ
17	§	¥À	zÀ	vÀ	UÀ	PÀ
18	§	¥À	zÀ	vÀ	UÀ	PÀ
19	§	¥À	zÀ	vÀ	UÀ	PÀ
20	§	¥À	zÀ	vÀ	UÀ	PÀ
21	§	¥À	zÀ	vÀ	UÀ	PÀ
22	§	¥À	zÀ	vÀ	UÀ	PÀ
23	§	¥À	zÀ	vÀ	UÀ	PÀ
24	§	¥À	zÀ	vÀ	UÀ	PÀ
25	§	¥À	zÀ	vÀ	UÀ	PÀ
26	§	¥À	zÀ	vÀ	UÀ	PÀ
27	§	¥À	zÀ	vÀ	UÀ	PÀ
28	§	¥À	zÀ	vÀ	UÀ	PÀ
29	§	¥À	zÀ	vÀ	UÀ	PÀ
30	§	¥À	zÀ	vÀ	UÀ	PÀ
31	§	¥À	zÀ	vÀ	UÀ	PÀ
32	§	¥À	zÀ	vÀ	UÀ	PÀ
33	§	¥À	zÀ	vÀ	UÀ	PÀ