ARE DIFFERENT HEARING AID SETTINGS REQUIRED FOR DIFFERENT LANGUAGES?

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DEDICATED TO

Amma,
Appa,
Kuttan
&
My Guide

CERTIFICATE

This is to certify that this masters dissertation entitled '**Are different hearing aid settings required for different languages?'** is a bonafide work in part fulfillment for the degree of Master of Sciences (Audiology) of the student with Registration No. 11AUD017. 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.

Mysore
May, 2013

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DECLARATION

This masters dissertation entitled ‘**Are different hearing aid settings required for different languages?’** is the result of my own study and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore **Registration No. 11AUD017**

May, 2013

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It's a **dream** *of watching and working with a person so* ***'Admirable'…..***

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CHAPTER 1

INTRODUCTION

‘With the gift of listening comes the gift of healing’

- *Doherty (2013), (excerpted from http://quotationsbook.com/quote/46696/).*

With the advent of advanced digital signal processing in hearing aids, the gift of near normal listening has been realized for many individuals with hearing impairment. According to Humes (1996), a ‘good’ hearing aid fitting must address the issues of optimizing audibility and intelligibility, avoiding loudness discomfort, matching preferred loudness levelsand providing good sound quality. These goals have led to the development of various digital algorithms incorporated in hearing aids and prescriptive formulae over the past several years.

The notable procedures used in the recent past are for selection of non-linear hearing aids include FIG6 (Killion&Fikret-Pasa, 1993), Desired Sensation Level - input/output (DSL i/o) (Cornelisse, Seewald, & Jamieson, 1995), National Acoustic Laboratory Non-Linear-1 (NAL-NL1) (Dillon, 1999) and National Acoustic Laboratory Non-Linear-2 (NAL-NL2) (Dillon, Keidser, Ching, Flax, & Brewer, 2010).

Most widely used prescriptive procedure in the clinical settings is NAL-NL1 (Aazh& Moore, 2007). This renowned procedure advocates on maximizing speech intelligibility based on two principles, namely normalizing loudness across frequencies and hearing loss desensitization. It is derived from an optimization procedure combining the Speech Intelligibility Index (SII) formula and loudness model (Moore &Glasberg, 1997). The NAL-NL1 is designed by incorporating the long-term average speech spectrum (LTASS) of English language. LTASS accurately reflects the acoustic characteristics of the speech signal actually received at the hearing aid microphone (Cornelisse, Gagne, &Seewald, 1991).

The LTASS across internationally spoken 12 languages such as English, Swedish, Danish, German, French, Japanese, Cantonese, Mandarin, Russian, Welsh, Singhalese, Vietnamese (Byrne, et al. 1994), Finnish (Kiukaanniemi, Soponen, & Manila,1982), Nepali (Pradhan&Nikam, 1994), Hungarian, Italian, Russian (Tarnoczy, 1971) and Polish (Zalewski&Majewski, 1971)and for Indian languages such as Hindi (Rupela&Manjula, 2002), Kannada (Sairam & Manjula, 2002), and Malayalam (Samuel & Yathiraj, 2002), showed a spectrum shape which was comparable to that of LTASS of English. That is, the energy drops off gradually towards the higher frequencies. This similarity in the spectral shape can be attributed to the fact that even though physical differences exist in vocal tract configuration across individuals' speaking different languages in the world, the average vocal tract dimensions are approximately identical (Chasin, 2012).

Inspite of the similarity in the LTASS across different languages, small but notable differences are reported to occur between different dialects of English and among different languages (Byrne et al.,1994). In consensus with the above finding, studies in Indian context also show that the overall levels mean values of average speech spectrum of Hindi (Rupela&Manjula, 2002), Kannada (Sairam & Manjula, 2002) and Malayalam (Samuel & Yathiraj, 2002) was higher than English, on an average of 7.33 to 9 dB HL in frequencies below 3 kHz. This difference was lesser for frequencies greater than 4 kHz. The LTASS measurement remains constant over time (Byrneet al.,1994) i.e., LTASS provides information on the distribution of energy across frequencies in a language over time. But, it does not provide a measure of the intensity changes over time. Thus, LTASS and its derivative (SII) account only for two dimensions of speech, i.e., spectral and intensity variations. The SII does not account for temporal component of speech (Humes, Dirks, Bell, Ahlstrom, & Kincaid, 1986). Due to this inherent shortcoming of SII, the SII cannot account for contextual variations, intensity changes over time across sentences (i.e., variations in intensity across word order), differences in vocal effort required to produce a specific language and timbre perception.

The acoustic feature of a language is firmly linked to specific characteristics it is endowed with, such as tonality (tonal vs. non-tonal language), morphology (agglutinative language vs. Fusional/Inflectional language), syntactic typology/ word order (Subject-Object- Verb vs. Subject-Verb-Object, i.e., SOV vs. SVO). Also, suprasegmental properties such as stress, rhythm, intonation, rate and length/quantity vary considerably across languages.

The distribution of energy over time is a significant factor in accounting for the intensity differences in word order across a sentence (Chasin, 2012a). Since, SII changes are typically frequency response changes, it is sensitive in addressing issues related to phoneme level variations, but it is not sensitive to information concerning word-level or sentence-level issues that may affect the electroacoustic settings of hearing aid required for different languages (Chasin, 2008; 2011).

Thus, there is a clinical concern about fitting hearing aids through SII as the issues arising due to third dimension of speech, that is, time is not dealt with SII. Hence, fitting amplification systems through the SII based measures might not prove to be effective in bi- / multi-lingual individuals who speak different languages, especially when there are substantial variations in word order between their first and second languages (as evident in Indian languages and English).

The Indian languages, such as Hindi and Kannada vary from English in terms of acoustical, morphological, syntactical and supra-segmental domains. It is also important to take into consideration the morphophonemic (frequency of usage of phonemes) differences between English (Kessler &Treiman, 1997) and Kannada (Ranganatha, 1982) languages. Since, such variations occur even at phonemic level between the two languages (Kannada & English), some changes can be expected in the LTASS. This in turn warrants a research question on the whether the universal LTASS (based on 12 languages across the world) isappropriate to be used for hearing aid users speaking Indian Englishand Kannada.

English follows a Subject-Verb-Object (SVO) structure, whereas Kannada follows Subject-Object-Verb (SOV) order as against SVO order of English. Objects, like all content nouns (subjects, pronouns, etc.) are more intense than function words such as verbs, prepositions, adverbs, adjectivesand conjunctions. Also, the intensity at the end of the sentence will always be softer than the initial part of the sentence simply because the air flow from our lungs is decreasing as we run out of air (Chasin, 2011).

The languages with a non-noun as the final item in the sentence (SOV languages) are more likely to be subjected to lower intensity at the end of utterance when compared to SVO languages which tend to end with a noun. Therefore,sentence-final audibility is an important factor which should be taken into account during hearing aid fitting for SOV languages that do not have nouns at sentence final position (Chasin, 2012 a). Hence, with respect to hearing aid fitting, it can be hypothesized that individuals speaking and listening to SOV languages (Kannada) would require more gain for soft level inputs (typically found in sentence final positions) than those speakers of SVO (Typical English) languages (Chasin, 2011).

Need for the study

As is evident from the plethora of studies, variations exist between English and Kannada (Kessler & Treiman, 1997; Ranganatha, 1982; Savithri, Goswami, &Kedarinath, 2007; Rao, Bharati, Sangal, &Bendre, 2002; Rathna& Bharadwaja, 1977). Selection of hearing aids by NAL-NL1(derived on the basis of LTASS & SII) for languages other than English may/may not address all the issues related to the audibility. Hence, there is a need to investigate whether the gain settings have to be set differently for different languages.

Since the hearing aid fitting formulae, especially NAL-NL1, are based on LTASS and SII measure which accounts for intensity variation across frequencies and not the intensity variations across the time, the changes in the input intensity to the hearing aid across time cannot be accounted. This is especially true for a SOV language where the intensity drops off at the end of the sentence. Hence, there is a need to investigate the influence of word order of a language in order to study the intensity changes across time in a sentence. This would substantiate the need to manipulate the gain settings of the hearing aid, to realize the optimal benefit from the same.

To realize the maximum benefit from the hearing aid, it has to be programmed to optimal settings. Hence, there is a need to understand if there is a change in the speech identification performance of the participants when the hearing aid is programmed in accordance with NAL-NL1, and when it is optimized for Indian English and Kannada through visible speech measurements and SII. Hence, the second objective was formulated to address the same issue that is, to compare the benefit derived from a hearing aid programmed to NAL-NL1, optimized to Indian English and optimized to Kannada settings. The data derived from the insertion gain measurements and visible speech measurements will facilitate a deeper understanding on the differences between the two languages in terms of gain differences and spectral variations respectively.

There is a considerable increase in the number of bilingual speakers in Karnataka from 1991-2001 (Government of India census, 2001). The proportion of population having English as their second language in Karnataka amounts to 28.44 % (Mallikarjuna, 2010). With the advent of English as the second language in schoolsand English as medium of instruction in the higher education systems in India, there is an ever increasing population with bilingualism (Mallikarjuna, 2010). However, inspite of increase in the bilingual speakers, there is a dearth of research in comparing the optimal gain requirements for a bilingual hearing aid users (especially for two languages differing in word order that is, SOV (Kannada) and SVO (Indian English). Therefore, the present study is one of the first of its kind to be carried out in the Indian context to provide an insight into the need (if any) for a new prescriptive formula for the Indian languages like Kannada which follow an SOV structure.

The differing gain settings could be verified by real ear and acoustic measures. The changes in such measures can be affected by different degrees depending on the speaker-related variability (such as language proficiency and articulation of the speaker); recording-related variability (including the distance of microphone from the mouth of the speaker, sensitivity and frequency response of microphone, the efficiency of software used for recording and the efficacy of the sound card used for recording); and nature of transmission channel/ environmental factors (such us ambient noise levels during testing). There exist several factors that can contaminate the reliability of the objective measures. In order to overcome such limitationsand to understand the correlation between objective real ear findings and perceptual measures, behavioural speech identification scores for sentences was measured.

Aim and objectives of the study

The study aims to investigate whether a hearing aid needs to be programmed differently for languages that use either SVO (English) or SOV (Kannada) patterns in a sentence. The specific objectives are as follows:

1. To compare the variations in intensity across sentences of Indian English, American English and Kannada, in order to appreciate the influence of word order.
2. To compare the variations in intensity across frequency, in order to understand the LTASS variations for sentences of Indian English, American English and Kannada.
3. To objectively evaluate the performance of the hearing aid with hearing aid programmed to three settings. They are hearing aid programmed with NAL-NL1 settings, optimized for Indian English sentences and optimized for Kannada sentences.
4. To compare the optimized hearing aid gain setting for Indian English and Kannada with NAL-NL1 prescription.
5. To evaluate and compare the perceptual outcomes of the hearing aid programmed to NAL-NL1, optimized for Indian English sentences and optimized for Kannada sentences.

Hypothesis

There is no significant difference in the amplification required for conversational level (45 dB HL) of sound inputs for SVO (English) and SOV (Kannada) languages.

CHAPTER 2

REVIEW OF LITERATURE

'The hearing ear is always found close to the speaking tongue'.

(Emerson, 1882; http://en.nordsprog.com/category/Hearing)

There is an intricate relationship between the long-term average speech spectrum (LTASS) and the language spoken by an individual. The LTASS provides a global measure of the acoustic characteristics of continuous discourse in a language (Noh & Lee, 2012). Language differences, though relatively to a small extent, are acknowledged as a source of variability in the LTASS (Ackerman, Hesterberg, &Bradlow, 2012). The LTASS is an integral part of most of the prescriptive procedures for hearing aid selection.

Bryne et al. (1994) investigated 12 languages (English, Swedish, Danish, German, French, Japanese, Cantonese, Mandarin, Russian, Welsh, Singhalese, & Vietnamese) across the world and reported that the LTASS of all these languages followed a similar spectral shape. Hence, he suggested using a singleuniversal LTASS and its dynamic range to represent all languages. However, literature reveals that long-term average speech spectrum (LTASS) has cross-linguistic equivalence in some studies, but systematic differences in others (Ackerman et al., 2012).

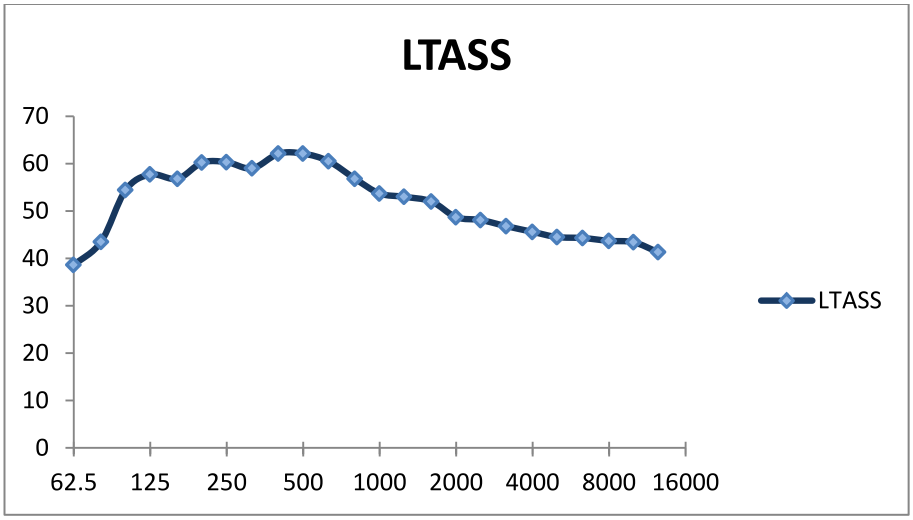


*Figure 2.1.*Representation of universal long-term average speech spectrum (LTASS) (Byrne et al., 1994).

Byrne et al. (1994) found that individual languages showed statistically significant variations, differing up to 3 dB in magnitude from the universal long-term average spectral values. Noh and Lee (2012a) measured the LTASS of Korean speakers and showed that there was a significant difference between Korean language and English, especially at high frequencies. Korean LTASS was on an average 5 dB lower than English in the frequencies ranging from 2 to 5 kHz, this difference was more than 5 dB above 6 kHz. Such differences in LTASS were also noted for tonal languages such as Cantonese. Wong, Ho, and Chua (2007) found that there was a difference in frequency importance weightage of Chinese when compared to English. While English has a relatively high band importance for mid- and high- frequencies (Kryter, 1962), Cantonese has high band weightages for low- and mid- frequencies. The authors attribute such variations to the tonal nature of the Cantonese language.

In consensus with the above finding, studies in Indian languages also show that LTASS (mean values) of Hindi (Rupela&Manjula, 2002), Kannada (Sairam & Manjula, 2002) and Malayalam (Samuel & Yathiraj, 2002) was higher than English. Sairam and Manjula (2002) measured the LTASS of Kannada using a standardized passage (story) and reported that the LTASS (mean values) of Kannada was higher than English on an average of 8.5 dB HL in low frequencies (< 1 kHz), 7.33 dB HL in mid frequencies (1 kHz - 3 kHz) and 2.25 dB HL at high frequency (> 4 kHz). Samuel and Yathiraj (2002) have also found that LTASS of Malayalam was on an average 9 dB HL higher than that of English at frequencies below 3 kHz. In their study, this difference was lesser at 4 kHz and above.

From the plethora of studies discussed above, it can be found that small but significant differences exist between English and other languages. The overwhelming source of variability in the LTASS is mostly 'speaker-specific'but relatively small, yet significant contributions from 'procedure specific' and 'language-specific'variations which cannot be ignored. Bryne et al. (1994) have suggested that the differences in the distribution of phonemes among the different languages might contribute to variations in LTASS. Therefore, when there are substantial variations in frequency distribution of phonemes between the different languages spoken by an individual (especially bilinguals and multilinguals), it can expected that LTASS will also vary.

Ackerman et al. (2012) reported that within the Mandarin-English bilinguals, consistent LTASS differences between Mandarin and English was observed. The authors observed that individuals with Mandarin as their first language (L1) and English as their second language (L2) also show variations in LTASS from the native English speakers, when speaking English. Thus, the authors conclude that, keeping the language constant mitigates some, but not all, of the observed L1 vs. L2 differences. This finding suggests that variations in LTASS are due to both contributions from both talker- (speaker-) specific and language-specific variations as well.

In a multilingual nation like India, L1 influencing the acoustic characteristics of L2 can be more rampant. There are 22 scheduled languages of India (Government of India Census, 2001). One such official language widely spoken in the southern part of India is Kannada. Ample differences in terms of phonemic composition of language exist between English (Kessler & Treiman, 1997) and Kannada (Ranganatha, 1982). In addition, there are differences in segmental and supra-segmental aspects.

2.1. Differences between English and Kannanda

English ranks as second widely spoken language in the world with about 480 million speakers (The Summer Institutes of Linguistics Ethnologue Survey, 2009), while Kannada, a Dravidian language widely spoken in Karnataka state of south India, has roughly 38 million native speakers (Government of India Census, 2001). It is one of the 40 most spoken languages in the world (Government of India Census, 2001).

Variations between the languages can be either language-specific and/ or talker-specific (i.e., physiological). e.g., Talkers with low-pitched voices in L1 will have low-pitched voices in all languages (Ackerman et al. 2012). Cutler and Ladd (1983) said that specific interactions and relation between suprasegmental and segmental aspects are the most salient characteristics that differentiate between languages. Segmental features refer to the basic inventory of distinctive sounds and the way in which they combine to form a spoken language; whereas suprasegmentals are those features that influence the way the sounds are processed for meaning (Mathew & Butt, 2010).

2.1.1. Supra - Segmental differences between Kannada and English.

Prosodic characteristics such as rhythm, stress and intonation in speech convey some important information regarding the identity of the spoken language. Findings from perception studies confirm that prosodic information, specifically pitch and intensity, are used for language identification under conditions where the acoustics of sound units are degraded (Mori et al., 1999).

2.1.1.1 Rhythm.

Languages can be broadly categorized as stress-timed, syllable-timed and mora-timed, based on their timing/rhythmic properties. English is a typical example for a language with stress-timed rhythm (Abercrombie, 1964), whereas Kannada is a mora-timed language (Savithri, Goswami, &Kedarinath, 2007). Abercrombie (1964) found that in stress-timed languages like English, duration of the syllables is mainly controlled by the presence of stressed syllables. Intervals between two stresses are said to be near-equal. Syllables that occur in between two stressed syllables are shortened to accommodate this property. In mora-timing, successive morae are said to be near-equal duration. Morae are sub-units of syllables consisting of one short vowel and any preceding onset consonants (Grabe& Low, 2002).

There are significant differences in inter-vocalic or inter-stressed intervals between syllables in Kannada language when compared to English. Grabe and Low

(2002) noticed that inter-vocalic interval of English is longer than syllable languages. Savithri et al. (2007) found that inter vocalic intervals are longer in Hindi (which is a syllabic language) when compared to Kannada. So, from the above findings of Grabe and Low (2002) and Savithri et al. (2007) it can be inferred that inter-vocalic interval of Kannada is shorter than English. This finding throws light on the fact that while fitting a hearing aid for different languages, rate of syllabic compression should be varied considerably, so as to account for the language specific vocalic and inter-vocalic intervals. A more rapid release time may be appropriate for those languages such that the less intense intervocalic consonants achieve sufficient audibility (Chasin, 2011).

2.1.1.2 Rate of speech.

Rate of speech affects both fluency and intelligibility. Andrews and Ingham (1971) reported that normal speaking rate in English language ranges from 115 to 165 words per minute (WPM) or 162 to 230 syllables per minute (SPM). A cross linguistic study of rate of speech in Hindi and Kannada languages by Rathna and Bharadwaja (1977) showed that the rate of speech in Kannada was 93 WPM or 429.67 SPM. The parameter of rate of speech can again have an effect on the dynamic settings of the hearing aid.

2.1.1.3 Stress.

Emphasis of the words and phrases in a sentence determines the stress pattern of the language. In languages like English, where the durational difference between short and long vowels is not very appreciable, incrementin fundamental frequency and amplitude signal serve as cues for stress (Lieberman, 1967). However, in languages like

Kannada, where durational cues predominate, the lengthened vowels act to serve as cue for stress (Savithri, Rohini, &Sairam, 2005).

An important feature of English intonation is the use of an extra stress to mark the focus of a sentence. This focus (termed as default ‘sentence stress’) falls on the last major word of sentence in English (Russell, 1997) where as in Kannada language, it reportedly occurs on the first few syllables (Manjula, 1997). The implication of this finding in programming of a hearing aid will be on the setting of the gain parameters and on adjusting the dynamic parameters i.e., attack time and release time in order to account for the variations of amplitude to cue stress in different languages.

2.1.2 Segmental differences between Kannada and English:

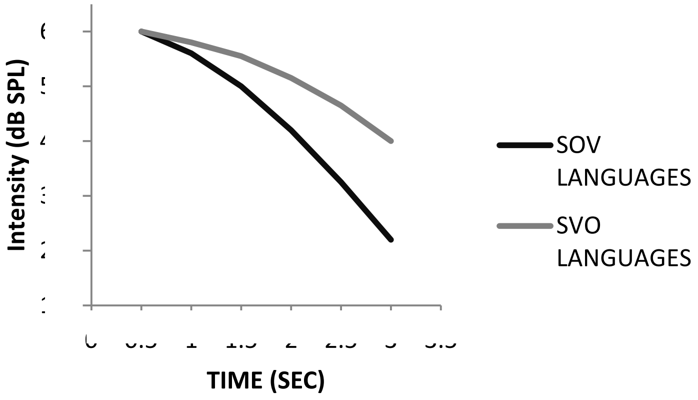
In addition to the above differences, considerable variations occur between Kannada and English at segmental level as well.

2.1.2 .1 Phonemic differences between Kannada and English.

Morphophonemic (frequency of use age of phonemes) differences exist between English (Kessler &Treiman, 1997) and Kannada (Ranganatha, 1982) languages. Ranganatha, (1982) did a classic study on the frequency of occurrence of phonemes in Kannada language and reported that the frequency of occurrence of the vowels is more than the consonants. Also studies on the acoustic characteristics (both spectral and temporal) of the Kannada language by Rajapurohit (1982) and Savithri (1989) showed that there are considerable variations in the acoustic characteristics of phonemes of Kannada when compared with English. Since, variations occur even at phonemic level, it might be reflected on LTASS as well. In addition to the differences in acoustic characteristics of these languages, the average sentence length in English (14.33 words) varies considerably from Kannada (7.79 words) (Rao, Bharati, Sangal, &Bendre, 2003).

In terms of word order, English follows a Subject-Verb-Object (SVO) structure. Kannada, on the other hand, follows Subject-Object-Verb (SOV) structure. Objects, like all content nouns (subjects, pronouns, etc.) are more intense than function words such as verbs, prepositions, adverbs, adjectivesand conjunctions. Hence in Kannada, like in all SOV languages (such as Hindi or Japanese and Korean), there is a falling intensity pattern across a sentence, as most of the sentences ends with a verb. It can be inferred that in Kannada, the final portion of the sentence will always be softer than word at sentence initial position.

This is substantiated by the findings of Chasin (2011) study where he quotes that at the end of sentence, the air flow from our lungs is decreasing as we run out of air.This decrease in the air flow is exacerbated when the sentence final item is a function word (non-noun) as found in SOV languages. In a longitudinal study (assessed over a year and a half) on 102 adult bilinguals, having their first language (Hindi, Urdu, Korean, Turkish, Iranian & Japanese) following SOV pattern and English as the second language, Chasin (2011) reported that SVO languages on average require approximately 3 dB greater gain (at 1000 Hz) than for a SOV language. Hence, Kannada falling in the same family of SOV word order pattern might also be subjected to the poor sentence-final audibility factor.



Note: Arbitrary values, Axes not scaled

Figure 2.2. Decrease in intensity as the end of a sentence is approached for English (SVO) and Hindi/Urdu or Japanese (SOV) language (From Chasin, 2011).

While the influence of word order on the sentence audibility is not exclusively studied in the Indian languages (which majorly follow a SOV pattern) specifically Kannada, few studies on the variation of intonation in sentence (amplitude cued along with pitch changes) are available in literature. One of the contemporary studies on the intonation pattern of declarative sentence in Chhattisgarhi speakers is reported by Kulshreshtha, Singhand Sharma (2008). They revealed that Chhattisgarhi speakers produce declarative sentences with a falling pattern.

Another note worthy study in the context of the Kannada language was by Mathewand Butt (2010). The findings of their comparative study on theterminal pitch contour for declaratives, exclamatory, interrogatives and imperatives revealed that, a falling contour was observed for the declaratives and imperative sentences. This finding was common for both male and female participants. Usually, lowering of pitch is accompanied by lowering of amplitude as well (Pierrehumbert, 1979). Hence, from the findings of Kulshreshtha et al. (2008) and Mathewand Butt (2010) falling pattern in the pitch across the sentence can be expected to be accompanied by a decline in the amplitude as well.

Thus, lowering of amplitude at the end of the sentence becomes an issue for concern as it can affect the optimal benefit derived from the hearing aid. Therefore, while fitting hearing aid in non-native English languages or for those languages that do not have nouns (or equivalently intense elements such as pronouns) in or near a sentence final position, audibility should be a matter of concern.

The languages with a non-noun in the final portion in the sentence (SOV languages) are more likely to be subjected to lower intensity at the end of utterance when compared to SVO languages which tend to end with a noun. With respect to hearing aid fitting, it can be hypothesized that people speaking and listening to SOV languages (Hindi and Kannada) would require more gain for soft-level inputs (typically found in sentence final positions) than those speakers of SVO languages (Chasin, 2011). The study by Achaiah and Narne (2011) support the above hypothesis. They reported that Kannada native speakers preferred an additional gain of 10 dB SPL compared to NAL-NL1, for sound input of 45 dB SPL.

From the above discussion, it is clear that Indian language such as Kannada varies from English in terms of acoustical, morphological, syntactical and supra-segmental domains. But, LTASS and its derivative (SII), primarily provide information about phoneme level issues and may not be sensitive to information concerning word-level or sentence-level (Chasin, 2011). These issues are of vital importance while prescribing hearing aid necessary for different languages. Hence, there is a need to investigate whether the gain prescribed by NAL-NL1 (derived on basis of LTASS/ SII for English) is adequate for Indian languages.

Therefore, with respect to hearing aid fitting, it can be hypothesized that individuals speaking and listening to SOV languages (like Kannada) would require differential gain settings than those speakers of SVO languages (like English). The current study is formulated with the aim of addressing this issue, i.e., ‘Are different hearing aid settings required for different languages?’

CHAPTER 3

METHOD

The present study was conducted to investigate whether a hearing aid needs to be programmed differently for languages that use either SVO (Indian English) or SOV (Kannada) patterns in a sentence.

3.1 Participants

Four groups of ears of bilingual individuals having Kannada as their mother tongue and English as their second language were included in the study. Group I included ten ears with mild (frequency PTA: 26-40 dB HL) hearing loss. Group II comprised of ten ears with moderate (4 frequency PTA: 41-55 dB HL) hearing loss. Group III comprised of ten ears with moderately severe (4 frequency PTA 56-70 dB HL) hearing loss. Group IV comprised of nine ears with severe (4 frequency PTA 71-90 dB HL) hearing loss.

All the participants of the study had either flat audiometric configuration (i.e., difference between maximum and minimum thresholds in the audiometric testing range was < 20 dB HL) or gradual sloping hearing loss (i.e., difference between successive octaves in the audiometric frequency range of <5-10 dB HL) (Lloyd & Kaplan, 1978; Pittman & Stelmachowicz, 2003).

3.1.1 Inclusion criteria.

The participants in the study were bilinguals (having Kannada as their mother tongue and English as their second language) diagnosed to have post-lingually acquired sensorineural hearing loss with an air-bone gap (ABG) of ≤10 dB HL). The age range of participants spanned from 15 to 58 years.

On otoscopic examination, all participants had ear canals that were free from cerumen, debris or foreign body. All the participants in the study had Speech Identification Scores (SIS) of not less than 52% and Uncomfortable Loudness Level (UCL) for speech of not less than 100 dB HL, in the test ear. Only participants whose hearing loss (at the time of testing), did not exceed five years were included in the study.

Their bilingual proficiency rating was equated using ‘Listening’ and ‘Speaking’ sub-sections of the screening tool ‘International Second Language Proficiency Rating’ (ISLPR) (Wylie & Ingram, 2006). Only participants who were exposed to English language from at least Grade 1 or I Standard were included in the study. The demographic data of the participants in the study are tabulated in Table 3.1.

Table 3.1.

Mean PTA (in dB HL), Mean SRT (in dB HL), Mean SIS (in%) and Mean age (in years)

Groups (N=39)	*PTA in dB HL Mean± (SD)*	*SRT in dB HL Mean ± (SD)*	*SIS in % Mean ± (SD)*	*Age in years Mean ± (SD, Range)*
I. Mild HL loss (N=10)	33.97 (3.79)	36.5 (4.74)	89.3 (7.92)	47.7 (9.72, 28-55)
II. Moderate HL (N=10)	47.97 (3.99)	48 (4.22)	88.6 (7.89)	45.5 (8.55, 30-55)
III. Moderately severe HL (N=10)	58.13 (3.38)	59.5 (4.97)	77.2 (9.05)	48.5 (9.08, 28-55)
IV. Severe HL (N=9)	75.46, 4.74	75 (5.27)	57.6 (4.3)	42.5 (12.51, 19-55)

The test ears had normal middle ear functioning as indicated by the middle ear analyzer, with an ‘A’ type tympanogram with the middle ear peak pressure ranging from +60 to -100 daPaand the admittance values ranging from 0.5 to 1.75 ml when recorded using the probe tone frequency of 226 Hz. The acoustic reflexes were recordable for lesser degrees of HL (all 10 ears in mild group, in 6 ears with moderate group and 2 ears in moderately severe group). It was absent for 21 ears (4 ears in moderate group and 8 ears in moderately severe group and all 9 ears in severe HL group). Reflex decay measured at 500 Hz and 1 kHz was negative in the participants who had recordable reflexes at the level of 10 dB SL (re: Acoustic reflex threshold or ART). Prior verbal informed consent was taken from the participants for the study.

3.1.2 Exclusion criteria.

Individuals having a history of middle ear infections, speech and language disorders and/or neurologic disorders, recruitment, retrocochlear pathology and/or auditory processing deficit (APD) and cognitive deficits were excluded from the study.

3.1.3 Test Environment.

All the tests were carried out in an acoustically treated air-conditioned single or double room set-up.

3.2 Equipment and Test material.

3.2.1 Instrumentation.

1. A calibrated two channel diagnostic sound field audiometer (Madsen Orbiter 922, version 2) with TDH 49 headphones housed in MX-41 AR ear cushions, B 71 bone vibratorand loudspeakers (Martin audio, London, C 115) positioned at 45^0 Azimuth at a distance of one meter from the participant was used. This arrangement facilitated the estimation of pure tone thresholds, speech audiometry, aided and unaided sound field speech identification testing and for routing/presenting stimulus for LTASS measurements.
2. A personal computer with Intel® Pentium®processor was connected to the auxiliary input of the audiometer for presentation of the recorded speech material. An immittance meter (Grason-Stadler, GSI-Tympstar) was used to rule out middle ear pathology.
3. A calibrated real ear test system (Fonix 7000 Hearing Aid Test System, version 1.8) was used for performing the real ear visible speech measurements.
4. A digital BTE hearing aid (four channel hearing aid, operated with a 13 size battery, frequency response from <200 Hz–6565 Hz, Maximum gain = 75 dB, Output saturation pressure level 90 (OSPL 90) = 106.2 dB SPL, Equivalent input noise (EIN) = 23.6 dB SPL, Current drain 0.9 mA/hand Total harmonic distortion (THD)< 7%) coupled with stock ear mould. The hearing aid had a fitting range from mild to severe degree of hearing loss. The hearing aid was programmed in non-linear mode. Additional features of the digital hearing aid i.e., volume control

was disabled. Other features such as noise reduction, compression threshold and compression ratio were set in default settings.

5. A personal computer, with NOAH 3 (version 3.1.3) and hearing aid programming softwares, connected to Hi-Pro was used to program the test hearing aid.
6. Recording microphone, personal computer loaded with ‘Computerized Speech Lab (CSL) model 4500’ software and ‘PRAAT version 4.6.09’software.

3.2.2 **Test material.**

The test material included list of material in Kannada, Indian English and English. These tests were used for measuring the variation of intensity over time, for measurement of LTASS and for aided sentence SIS. The details of the material are provided in Table 3.2.

Table 3.2.

Test material used for different languages.

		Acoustical LTASS measures		
S N	*To measure*	*Indian English*	*Kannada*	*American English*
1.	Intensity variation across sentence over time	50 sentences -5 lists of ten sentences each - suitable for Indian context from Standardized Phonemically Balanced Hearing In Noise Test, (Nilsson, Soili& Sullivan, 1994) - recorded in both adult Male and Female voice	50 sentences - 5 lists of ten sentences each - Phonemically Balanced sentences in Kannada, All India Institute of Speech and Hearing Research Fund (ARF) project, (Geetha & Sharath, 2012) - recorded in both adult Male and Female voice	50 sentences - Initial 5 lists of 10 sentences each from IEEE (1969) - Pre-recorded in Male voice only
2.	Long-term average speech spectra (LTASS)	- Same as above	-Same as above	- Same as above

		Real ear measures		
SN	*To measure*	*Indian English*	*Kannada*	*American English*
3.	Aided Long-term average speech spectra (LTASS)	- List of ten sentences for each setting	- List of ten sentences for each setting	- Not applicable
4.	Aided sentence identification score and optimizing hearing aid (preferred gain settings)	- Same as above	- Same as above	- Not applicable

The speech material used for measuring the intensity change across the languages i.e., Indian English and Kannada comprised of 50 sentences each recorded both in female and male voices, whilst for American English, 50 IEEE sentences extracted from a recorded CD material (Loizou&Philipos, 2007) were used. Thus, a total of 100 sentences each in Indian English and Kannada (50 sentences recorded in female voice and 50 sentences in male voice) and 50 sentences in American English were subjected for acoustical analyses i.e., to measure intensity variations across in the sentence across time and frequency.

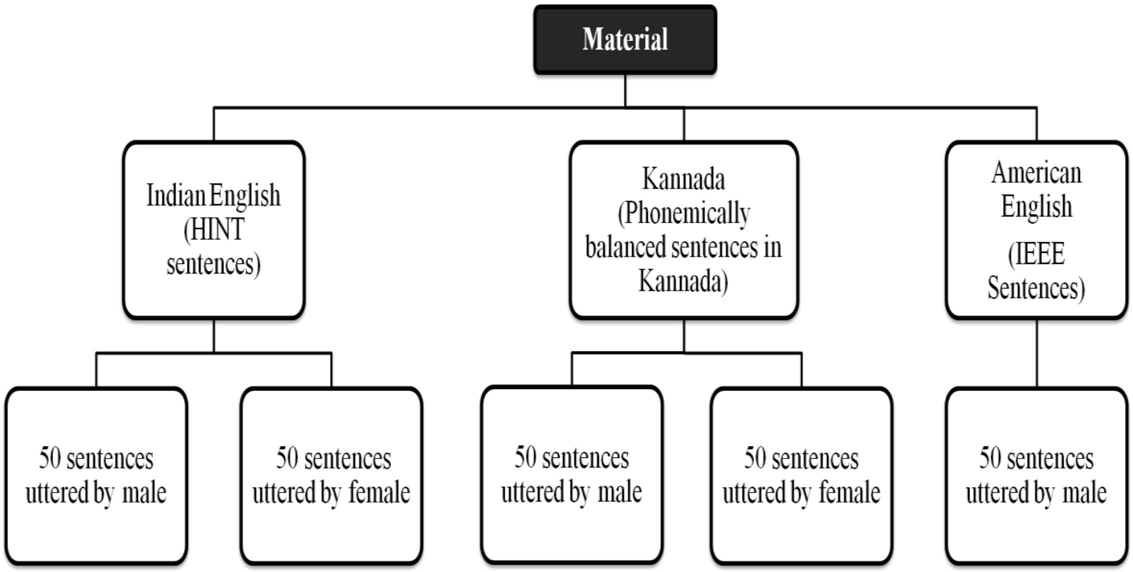


*Figure 3.1.*Details of test material used in the study.

The Indian English and Kannada stimuli were recorded with the microphone (Shure SM 48, Dynamic LOZ, AUD-535 Ms model, with the Cardioid polar pattern and frequency response till 20 kHz) kept 6 cm away from the mouth of the speaker. The recording was done in a sound treated chamber through the use of a personal computer loaded with Computerized Speech Lab (CSL) software. A mono recording of the stimuli was done using a 32 bit resolution and a sampling rate of 44,100 Hz. The recorded materials were group normalized to ensure that all the stimuli had equal loudness. Goodness testing of the recorded stimuli was done on six speech language pathologists having normal hearing who reported that the stimuli were clear. All stimuli were stored in the personal computer.

For the aided speech identification scores, the inter-sentence interval was maintained as 4 seconds. Each list included 10 sentences (test items) and initial 2 practice sentences, to ensure task familiarization. A calibration tone (1 kHz) was recorded before the stimuli. All the stimuli were stored in the personal computer. For the LTASS measurements, all pauses and silent sections in between two sentences i.e., inter-sentence interval, were removed. This was done in order not to account for the variations that occur in the speech spectra when the pauses were present.

3.3 Procedure.

Preliminary procedures included otoscopy and audiometric evaluation. The audiometric testing was performed using a calibrated audiometer. Pure tone audiometric thresholds were obtained using modified Hughson-Westlake procedure (Carhart & Jerger, 1959) across frequencies from 250 Hz to 8000 Hz for air-conduction and 250 Hz to 4000 Hz for bone -conduction (Mastoid placement). The minimum intensity (dB HL) at which the individual (threshold) was able to respond was noted as thresholds. The four frequency average was obtained for 500, 1000, 2000 and 4000 Hz in order to categorize and classify the test ears in different degrees and groups.

Speech audiometry including determination of Speech reception threshold (SRT), Speech Identification scores (SIS) and Uncomfortable loudness level (UCL) were carried out. For SRT, the paired words in Kannada developed by Rajasekhar (1976) were presented at 20 dB SL (re: PTA). The participants were asked to repeat the paired words, while the intensity was varied in terms of +5 and -10 dB steps. The minimum intensity at which the participant repeated at least two out of three spondees correctly was considered as SRT.

Speech identification score was measured at 40 dB SL (re: SRT) using the PB words in Kannada developed by Yathiraj and Vijayalakshmi (2005). The participants were instructed to repeat the words presented. Each correct response was given a score of 4%. The total correct response was calculated and termed as speech identification score. The maximum tolerable level of the stimuli measured in dB HL was noted as UCL. The test findings of all conventional audiological procedures were interpreted with the aim of understanding the degree and type of hearing loss.

All the participants in the study also underwent immittance testing i.e., Tympanometry and Reflexometry including reflex decay measurements to ensure normal middle ear functioning. Tympanometry was carried out using a probe tone at 226 Hz. This was followed by acoustic reflex measurements at 500, 1000, 2000 and 4000 Hz, ipsilaterally and contralaterally. Whenever possible, reflex decay test was also carried out.The participants fulfilling the selection criteria were included in the study.

For aided sentence identification scores and visible speech sound field measurements, the output from the personal computer was routed through a two channel audiometer (Madsen OB 922). The VU meter was adjusted with the 1 kHz calibration tone. The stimuli were presented through the loud speakers kept at a distance of one meter and 45^0 Azimuth from the participant, at an intensity level of 40 dB HL. The participants were instructed to verbally repeat the sentences heard after each presentation. All the participants were encouraged to guess when unsure of the word or words in the sentence.

For the purpose of evaluating the objectives of the study, data was collected in four phases. Phase I comprised of measuring and comparing the intensity differences in a sentence over time for the two dialects of English (Indian English & American English) and Kannada. The Phase II consisted of programming and optimizing the hearing aid for Indian English (IE) and Kannada (K) languages. Phase III consisted of measuring the LTASS and SII in visible speech mode when the hearing aid programmed to NAL-NL1, optimized for Indian English and optimized for Kannada. Phase IV consisted of measurement of SIS for sentences.

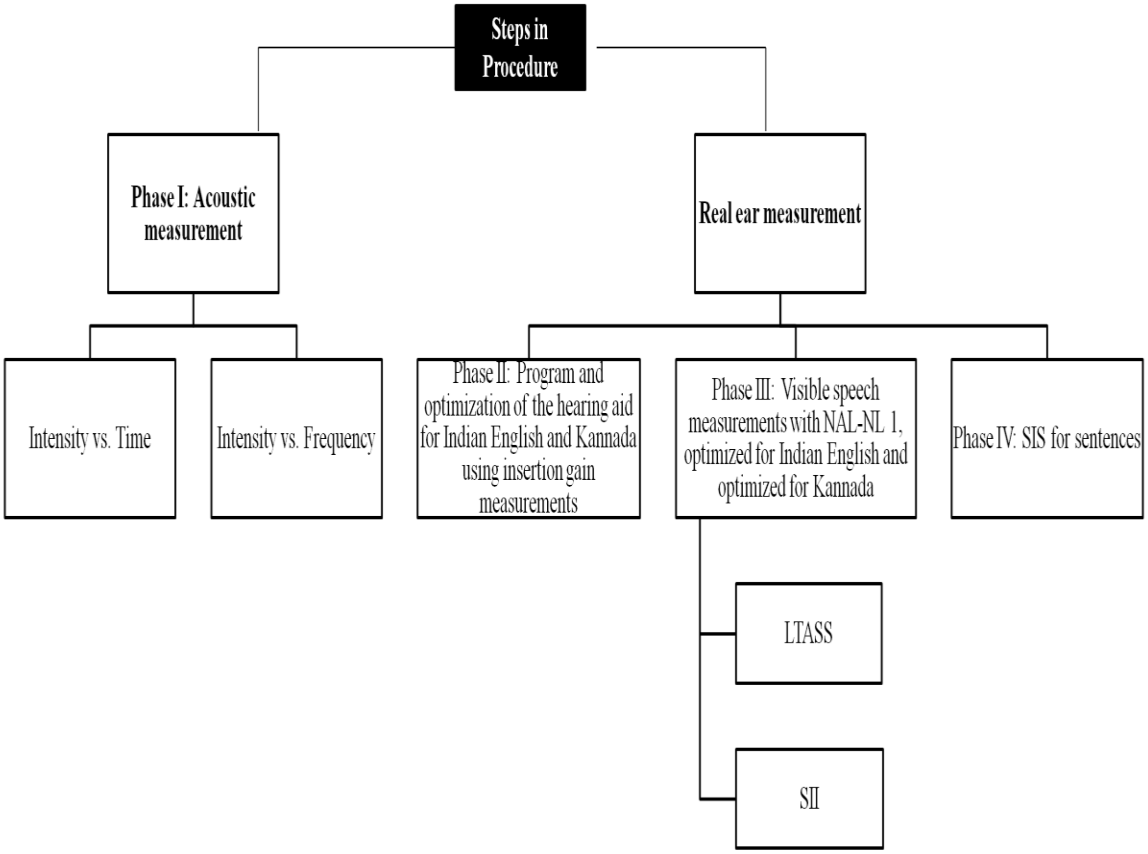


Figure 3.2. Flow chart of the four phases involved in data collection

3.3.1. Phase I: Measurement and comparison of the intensity differences in a sentence over time for the two dialects of English (Indian English & American English) and Kannada.

3.3.1.1Intensity vs. Time.

The SII does not account for intensity variations across time in a sentence. Hence, the Phase I of the study involved investigating the word order effect on intensity differences across the sentences in different languages using different patterns (SOV, SVO) i.e., Indian English, American English and Kannada. Sentences excerpted from the standardized lists (as discussed earlier) having the same length, were subjected to acoustic analysis using waveform editing procedure with the help of PC loaded with the PRAAT software.

Changes in the intensity of waveforms over time were analyzed for each of the sentences. Such an analysis was aimed at providing a clearer understanding of relative intensities of different units of sentence (initial, medial and final). Each sentence length was computed by marking the cursor at the initial and final part of the sentence. This resulted in the computation of the overall duration, which was measured in seconds. The fraction thus obtained was used to segment the sentence into three parts (initial, medial and final) having equal intervals. The data thus obtained, were utilized in identifying the variation in input intensity given to the hearing aid across the length of the sentence.

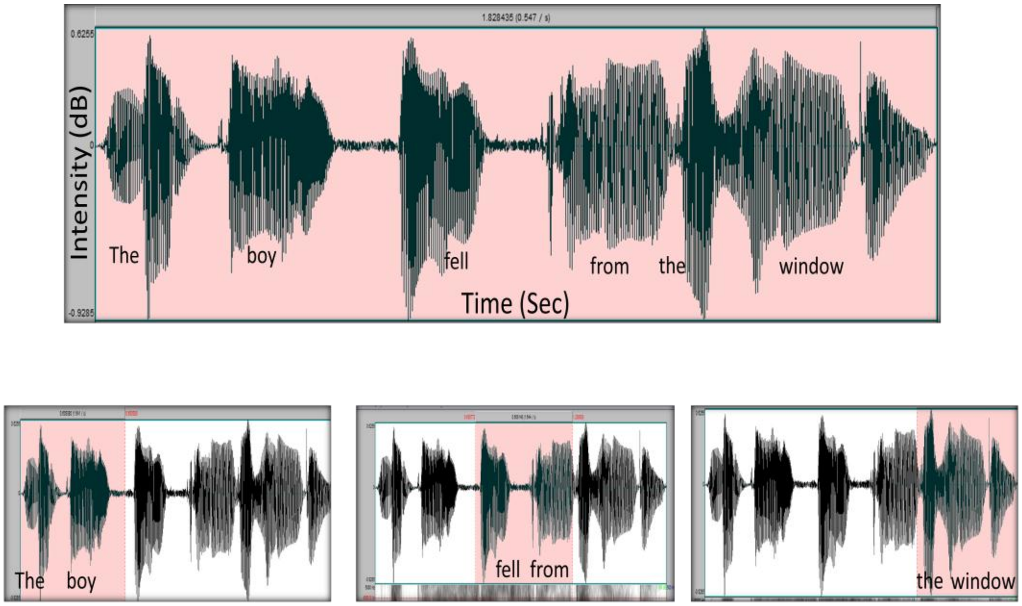


Figure 3.3.Waveform of a sentence (top panel); Initial, medial and final portions of the sentence adopted for measurement of variation of intensity across a sentence.

3.3.1.2Intensity vs. Frequency.

50 sentences each in the dialects of English (Indian English, American English) and Kannada were edited together to comprise into a single file, in adobe audition version 3.1. The inter sentence interval was deleted and thus obtained file was subjected to LTASS measurement for the same was done using the program written in the ‘Matrix laboratory (MATLAB) version 7.9.0.’ software.

3.3.2. Phase II: Programming and optimization the hearing aid for Indian English and Kannada languages.

Phase II of the study involved programming and optimizing the hearing aid. This was done in two steps:

i. Programming the test hearing aid

ii. Real ear insertion gain (REIG) measurement for verification of hearing aid fitting with reference to NAL-NL1 target gain curve at 65 dB SPL.

3.3.2.1. Programming the test hearing aid.

Commercially available digital BTE hearing aid with a fitting range of mild to severe hearing loss was selected. The digital hearing aid was connected through a Hi-Pro to the Personal Computer (PC) with the software for programming the hearing aid. After the hearing thresholds were fed into the software (NOAH-3.0), the digital hearing aid was programmed based on the NAL-NL1 prescriptive procedure (First Fit) with acclimatization level set at 2.

3.3.2.2. Optimization of NAL-NL1 hearing aid settings using real ear insertion gain measurement.

Real ear insertion gain measurement was done to ensure that the gain provided by hearing aid at the ear level was in accordance with NAL-NL1. For the verification purpose, the hearing aid gain was optimized such that it matched the target curve (65 dB SPL) prescribed in accordance with NAL-NL1.

For this purpose, ANSI digital speech was presented from the loud speaker of the real ear test system (Fonix 7000) located at 45^0 Azimuth and at a distance of one foot from the test ear of the participant. Insertion gain measurement was performed using pressure method. In this method, the reference microphone is placed as close as possible to the hearing aid microphone while the measurement is being done. The reference microphone monitors the SPL reaching the hearing aid from the loudspeaker. Suring leveling of the system, if the input level is higher or lower than the desired output level, the reference microphone and the regulating circuitry automatically turned the volume of the sound coming from the speaker down or up, until the required level is obtained during the process of levelling.

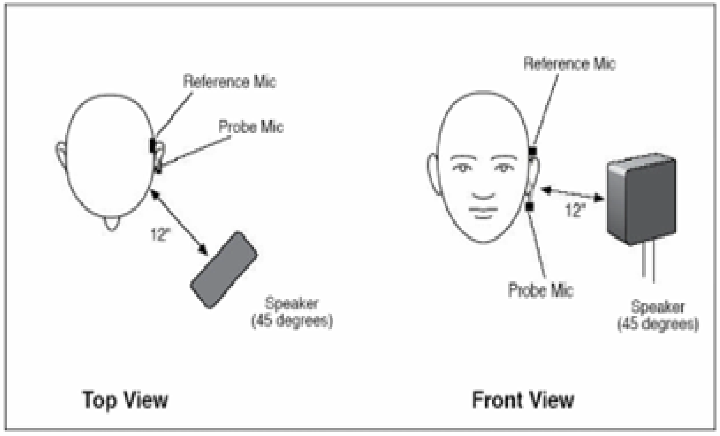


*Figure 3.4.*Location of the loudspeaker and the participant for real ear measurement.

3.3.2.2. (A) Insertion Gain Measurement Procedure.

Fonix 7000 was connected to the personal computer for visible speech measurement. The step-wise procedure given below was used for insertion gain measurement through Fonix 7000.

1. The instrument (Fonix 7000) was switched ‘on’.
2. Sound field levelling of the instrument was ensured before carrying out the insertion gain measurement.
3. From the opening screen, the real ear navigation was accessed in the Fonix 7000 module. Later, the insertion gain measurement mode was used.
4. Marking the probe tube for insertion gain measurement:

   The ear mould was held next to the probe tube, so that the tube rested along the bottom of the canal part. The length of the probe tube extending past the canal opening was 5 mm. The probe tube was marked at this point with a marker pen. The probe tube was attached tothe bodyof the probe microphone. The probe microphone was attached to Velcro pad on the integrated ear hook.

5) Placement of ear hook, reference microphone and probe microphone:

The integrated probe microphone was positioned on the test ear of the participant. The reference microphone was secured on the ear hook above the ear. The ear hook slider was adjusted up or down for optimal positioning of the probe tube into the ear, as shown in the Figure 3.5. The probe tube was inserted into the ear of the participant (without the ear mould or aid). It was ensured that the marking on the probe tube was at the entrance of the ear canal – between the tragal and antitragal notch.

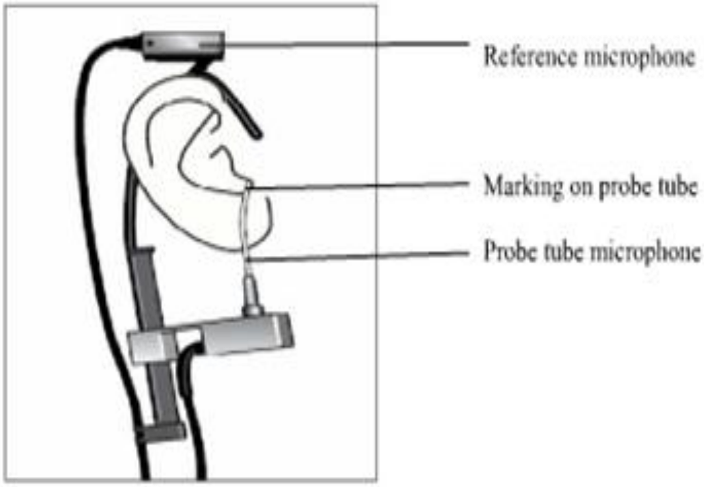


*Figure 3.5.*Placement of reference microphone and probe tube microphone.

3.3.2.2. (B) Measurement of Real Ear Unaided Gain (REAG).

Once the equipment was set-up, the traditional real ear measurement was carried out using Fonix 7000. The unaided measurement was carried out by selecting 'Unaided' from 'Real Ear Aided Gain' sub-menu. The unaided measurement for ANSI digi speech signal at 65 dB SPL was carried out.

Table 3.3.

Protocol for REUG and REAG

Protocol for REUG and REAG	
Type of stimulus	ANSI Digi-Speech
Level of stimulus	65 dB SPL
Location of integrated probe microphone set	Participant's pinna
Reference microphone	Enabled, located over pinna
Prescriptive formula	NAL-NL1
Output limiting	125 dB SPL

3.3.2.2. (C) Measurement of Real Ear Aided Gain (REAG).

The protocol shown in Table 3.3 was followed for REAG measurement. The hearing aid was fitted in the test ear of the participant without disturbing the length of probe tube in the ear canal. The hearing aid was switched on. It was ensured that the stock ear mould fitting was good and there was no feedback.

The probe tube microphone in the aided ear canal picked up the sound from the ear canal for REAG measurement. During the measurement, it was ensured that the REAG matched the NAL-NL1 targets at most of the frequencies. This was done by optimizing the hearing aid gain across channels to meet NAL-NL1 the target at moderate level input (at 65dB SPL).

The REIG in the test ear was measured by subtracting the real ear unaided gain (REUG) from the real ear aided gain (REAG) in the ear canal (i.e., REIG = REAG-REUG). At the end of this stage, the REIG data across the frequencies low frequency (500

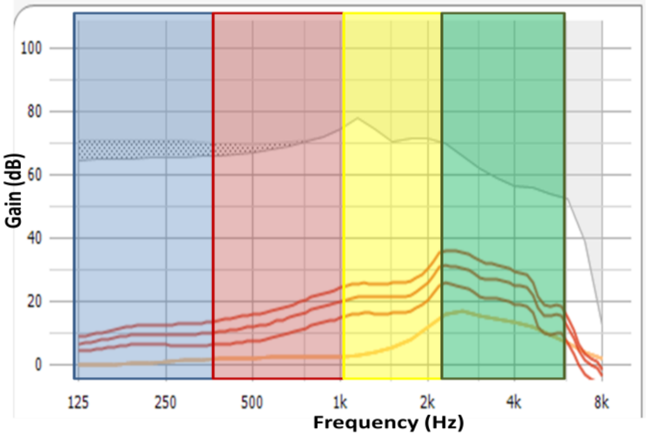
Hz, 800 Hz & 1 kHz) ; mid frequency (1.5 kHz & 2 kHz) ; and high frequency (3 kHz & 4 kHz) were tabulated for each participant for the purpose of analysis.

3.3.2.3 Optimizing the hearing aid gain for Indian English and Kannada languages and obtaining insertion gain for the same.

Once the aided LTASS and SII were obtained for unaided and aided (with hearing aid programmed to NAL NL-1) conditions, optimization of the hearing aid fitting was done for specific languages (i.e., Indian English and Kannada).

Optimization was first done for Indian English sentences. The recorded HINT sentences were played through the loudspeaker connected to the audiometer placed at 45^0 Azimuth and at a distance of one meter from the participant. The participant was asked to rate the intelligibility of the sentences. Based on the feedback from the participant, the hearing aid was fine-tuned across the four channels in such a way that gain in low frequencies (0.3 kHz & 1 kHz), mid frequency (2.5 kHz) and high frequency (5.5 kHz) were manipulated until the participant reported that most of the sentences presented were intelligible (Figure 3.6). These settings were stored as Program 1 (optimized for Indian English). With the gain settings of hearing aid in Program 1, aided real ear gain measurements were carried out.

The above step was repeated for optimizing the hearing aid for Kannada sentences. These settings on was stored in the hearing aid as Program 2. The aided real ear gain was obtained for the same, using ANSI digi speech delivered through Fonix 7000 loud speaker at 65 dB SPL. Similar to the NAL-NL1 insertion gain measurement, insertion gain was obtained for hearing aid optimized for Indian English and Kannada languages by subtracting REAG – REUG.



Note: Low- (0.3 kHz and 1 kHz); mid- (2.5 kHz) and high- (5.5 kHz) frequencies

*Figure 3.6.*Target gain across 4 channels of HA

3.3.3. Phase III*. *Visible speech measurements.

Once, the insertion gain measurements were carried out, and thus ensured that hearing aid gain was verified such that it suits the NAL-NL1 prescription, the Visible speech measurement mode was chosen. The Visible Speech feature is a special feature used for performing real ear measurements with live-/recorded- speech or any other external source types. A visible speech measurement gives the real-time response of the hearing aid to the speech signal, i.e., the average response of the hearing aid over the time of the test and the maximum and minimum amplitudes of each frequency band. In addition to this, the SII is also displayed. Thus, Visible speech measurement provides an insight on the audibility of the speech sounds at the level of ear canal of the participant without or with hearing aid.

Visible Speech Measurementwas carried out in a double room situation. The participant was seated in the testing room and the examiner operated the presentation of speech material through personal computer connected to the auxiliary input of the audiometer in the control room. The participant was seated in the calibrated position in the sound field with speech material (10 Kannada sentences, 10 sentences from HINT in English recorded in Indian speaker’s voice) with no silence or interval between the each sentence was presented through the loud speaker of the audiometer positioned at 45° Azimuth and at a distance of 1 meter from the head of the participant. Leveling of the Fonix 7000 hearing aid testing system was not required for the measurement of visible speech as the signal was not presented through the loudspeaker of the Fonix 7000. Similar to the insertion gain measurements, probe tube fitting was done.

The recorded HINT English sentences (list of 10 sentences) and Kannada sentences (list of 10 sentences) were played through Adobe Audition 3.0 player loaded in personal computer and were routed through auxiliary input of the audiometer to the loudspeaker, at conversational level i.e., 45 dB HL (Byrne, Dillon, Ching, Katsch, & Keidser, 2001). The VU meter deviation was monitored to ensure that it did not exceed an average deflection of 0 dB on the scale.

The Table 3.4 shows the settings of the parameters (protocol) for the measurement of visible speech and SII.

Table 3.4.

Protocol for visible speech and SII

Protocol for visible speech and SII	
Type of stimulus	Kannada standardized sentences (i.e., List 1 having 10 sentences)
Mean stimulus duration	Kannada standardized sentences: 30 seconds (approx.) HINT English sentences: 20 seconds (approx.)
Inter-sentence interval	Nil
Level of stimulus	65 dB SPL
Location of integrated probe microphone set	Participant's pinna
Reference microphone	Enabled, over the pinna
Prescriptive formula	NAL-NL1
Output limiting	125 dB SPL

3.3.3.1 Performing Visible Speech Measurements.

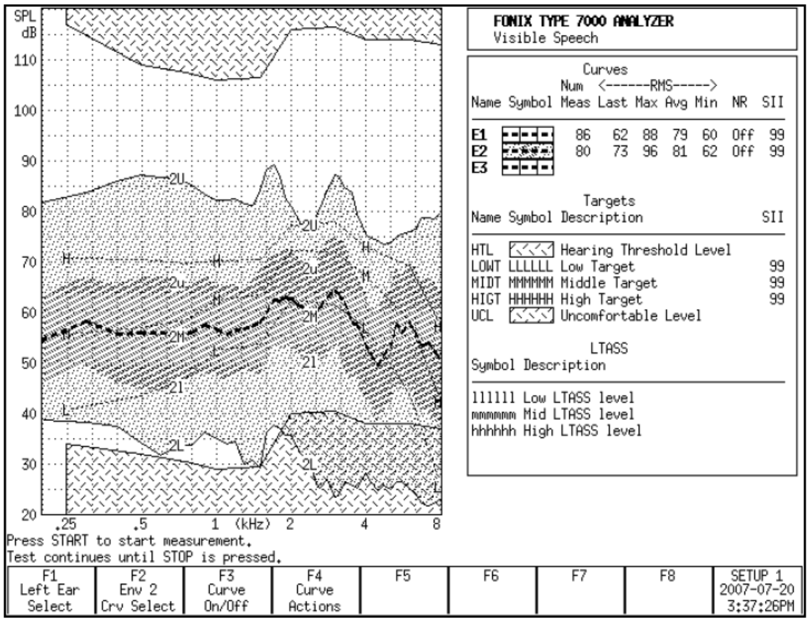
1. The audiogram of the participant was entered into the analyzer on selecting 'audiogram' displayed on the main menu. Both the air-conduction and bone-conduction thresholds were entered to generate the real ear target based on NAL-NL1 rule.
2. Once the audiogram was entered, real-ear measurement was accessed.
3. The Visible Speech (VS) screen was later selected.
4. The external signal, Kannada sentences/ English HINT sentences was played through Abode Audition 3.0 installed in the computer. This was routed through a

calibrated audiometer. The output from audiometer was given to the loudspeaker. This signal was picked up by the probe microphone (unaided) or microphone of hearing aid (aided) worn by the participant seated in the test position.

5. After the preliminary set-up, the Visible Speech measurement on the Fonix 7000 analyzer was initiated.

(a) Viewing the Real-time Visible Speech Display.

The Visible Speech measurement provided the real-time response of the hearing aid. Thevisible speech measurement was initiated as soon as the recorded material (all the 10 sentences of the list) was played through the audiometric speaker and thevisible speech measurement was stopped when the average response curve was stabilized. On completion of the visible speech measurement, the following curves were displayed on the visible speech screen as shown in Figure 3.7.Figure 3.7 shows the LTASS on the Visible speech screen after the completion of measurement.



```
FONIX TYPE 7000 ANALYZER
Visible Speech

                      Curves
             Num  <------RMS----->
Name Symbol  Meas Last Max Avg Min   NR  SII

E1   ▭▭▭      86   62  88  79  60   Off  99
E2   ▨▨▨      80   73  96  81  62   Off  99
E3   ▭▭▭

                      Targets
Name Symbol Description                  SII

HTL  ▨      Hearing Threshold Level
LOWT LLLLLL Low Target                    99
MIDT MMMMMM Middle Target                 99
HIGT HHHHHH High Target                   99
UCL  ▨      Uncomfortable Level

                      LTASS
Symbol Description

llllll Low LTASS level
mmmmmm Mid LTASS level
hhhhhh High LTASS level
```

```
Press START to start measurement.
Test continues until STOP is pressed.
```

```
2007-07-20
3:37:26PM
```

Figure 3.7. Visible speech screen on the completion of measurement

1. 2U - Represents the maximum response per frequency over the time of the test.
2. 2u - Represents the upper boundary of the standard deviation around the average frequency response.
3. 2M - Represents the average frequency response of the test.
4. 21 - Represents the lower boundary of the standard deviation around the average frequency response.
5. 2L - Represents the minimum response per frequency over the time of the test.

3.3.3.2 Aided Visible Speech Measurement.

The visible speech measurements were done with the hearing aid programmed and verified through IG measurements (in accordance to NAL-NL1 at 65 dB SPL target curve). LTASS and SII measures were obtained for both Indian English and Kannada sentences. The following parameters from the measurement screen were noted and the same were tabulated for the analyses.

i. Response amplitude of visible speech spectrum measured at 0.5 kHz, 0.8 kHz and 1 kHz (low frequency); 1.5 kHz and 2 kHz (mid frequency); 3 kHz and 4 kHz (high frequency) and average (difference between maximum and minimum amplitude from 0.2kHz to 8 kHz) in dB SPL.
ii. Speech Intelligibility Index (SII) (re: ANSI S3.5 - 1997), a value ranging from 0 to 100 as measured in Fonix 7000 system.

3.3.2.4. LTASS and SII measurements for hearing aid set to optimized settings for Indian English and Kannada languages:

Once the aided LTASS and SII were obtained for hearing aid programmed to NAL-NL1 setting, the same method is carried out for the hearing aid programmed to the optimized Indian English and Kannada setting as well.

3.3.4. Phase IV: Measurement of SIS for sentences

In order to verify the effect of hearing aid set to optimizedprogram setting, the subjective measure of aided Speech Identification Scores (SIS) for English and Kannada sentences were also obtained. The order of language being tested was randomized across the participants while testing aided Sentence Identification Scores to overcome the order effect. This subjective measure was targeted to provide an understanding on the perceptual impact of optimized setting and for correlating the same with the objective visible speech and SII measure.

The closed-set Speech Identification Scores for Sentences (SIS) in quiet were obtained through recorded HINT for Indian English and phonemically balanced Kannada sentence list (Geetha & Sharath, 2012) recorded in female voice was used. Review of literature (Bradlow, Torretta, &Pisoni, 1996; Hazan& Markham, 2004) suggests that female speakers articulate more clearly and have higher intelligibility than males. The stimuli were presented through a loudspeaker of the audiometer from 45^0 Azimuth placed at a distance of one meter from the head of the participant.

The response mode was verbally repeating the sentence. A total of 2 practice sentences were given to the participants before starting the testing. The scoring was done based on verbatim repetition of the sentence. A score of 1 was given for every correct repetition of sentence. This was done for hearing aid set to NAL-NL, optimized English and optimized Kannada. Raw scores were tabulated and subjected to statistical analysis.

3.4 Statistical analyses

The following data were tabulated and subjected to appropriate statistical analysis using Statistical Package for Social sciences (SPSS version 17.0).

1. Acoustical analysis was performed to account for the variations in intensity across time and frequencies in the sentence. This included analyses of
   a. Intensity change at initial, medial and final portions of the sentence (Time vs. intensity),
   b. Intensity change across frequencies, i.e., LTASS (Frequency vs. intensity).

Descriptive statistics (Mean, S.D&Range) was used for acoustical analysis. For, time vs. intensity measure, Mixed ANOVA was performed since there was both within and across subject factors i.e.,gender was across subject factor; languages (Indian English, American English & Kannada) and portions of the sentence (initial, medial, final) as the within subject variable.

For, frequency vs. intensity, the same was done with the exception of using the RMS amplitude at low, mid and high frequencies (LTASS) instead of the portions of sentences. Mixed ANOVA was done to find out if there was any main effect and if there were any significant interactions. Bonferroni adjusted multiple pair-wise comparison was done for within subject factors, when indicated.

2. To measure the difference in gain at the ear canal level for Verified NAL-NL, optimized Indian English and optimized Kannada settings, the Insertion gain data measurements in dB SPL was utilized.

   For, Insertion gain measurements, Mixed ANOVA was performed with degree of hearing loss as the across subject factor, frequencies (low, mid and high) and conditions (Verified NAL-NL1 setting, optimized settings for English and optimized settings for Kannada) as within subject factors. This was done to find out if there was any main effect and if there were any significant interactions. Post-hoc Duncan test was done for the degree of hearing loss and Bonferroni adjusted multiple comparison was done for within subject factors, when indicated. Repeated measures ANOVA was done to analyze the difference across of the conditions (Verified NAL NL-1 setting, optimized settings for English and optimized settings for Kannada).

   As significant interactions existed between the within subject and/or across subject parameters,repeated measures ANOVA was done to study the effect of each parameter separately on the dependent variable (score in different conditions: Verified NAL NL-1 setting, optimized settings for English and optimized settings for Kannada). Therefore, Repeated measures ANOVA was done separately for each frequency (low-, mid- and high- frequency) and degrees of hearing loss (mild, moderate, moderately-severe and severe).

3. In the real ear, the amplitude variations across the frequencies was tabulated from the LTASS data computed using visible speech measurements in three conditions i.e., NAL-NL1, optimized setting for Indian English and Kannada were considered.

For, aided LTASS, Mixed ANOVA was performed with degree of hearing loss as the across subject factor, frequencies (low, mid and high), languages (Indian English and Kannada) and hearing aid settings (NAL-NL1 setting, optimized settings for Indian English and optimized settings for Kannada) as within subject factors. This was done to find out if there was any main effect and if there were any significant interactions.

As significant interactions existed between the within subject and/or across subject parameters, the Repeated measures ANOVA was to study the effect of each parameter separately on the dependent variable. Repeated measures ANOVA was done separately for each degree of hearing loss (mild, moderate, moderately-severe and severe) across each frequency (low-, mid- and high- frequency). This yielded how different the Indian English was from K across frequency for 4 degrees of hearing loss with the 2 hearing aid settings (NAL-NL1& optimized).

4. Likewise, to account for the measure of intelligibility at the ear canal level, data on SII for NAL-NL1, optimized setting for Indian English and Kannada derived from Fonix 7000 visible speech measurements was utilized.

   Mixed ANOVA was performed with degree of hearing loss as the across subject factor, languages (Indian English& Kannada) and hearing aid settings (NAL-NL1 setting, optimized settings for Indian Englishand optimized settings for Kannada) as within subject factors. This was done to find out if there was any main effect and if there were any significant interactions. Since, significant interactions occurred; each degree of hearing loss was studied separately. Paired sample t-test was used to compare the difference between languages. This was done for each degree of hearing loss separately.

5. In order to correlate the objective measures (LTASS and SII) with the perceptual intelligibility measure, data obtained through behavioural Sentence Identification Scores (SIS) testing for NAL-NL1, optimized setting for Indian English and Kannada were subjected to analyses.

For behavioural sentence identification scores analyses, Mixed ANOVA was done with the conditions that is NAL-NL1 settingand optimized hearing aid settings for the two languages Indian English and Kannada (within subject variables) and the degree of hearing loss as across subject variable. When significant interactions were found, Repeated measure ANOVA was done for each condition across languages. This was also done for each degree of hearing loss separately.

CHAPTER 4

RESULTS AND DISCUSSION

The aim of the current study was to examine whether the hearing aid needs to be programmed differently for languages differing in word order in the sentence, i.e., English which follows Subject-Verb-Object (SVO) and Kannada which follows a Subject-Object-Verb (SOV) structure. The four specific goals of the study were

1. To compare the variations in intensity across sentences of Indian English, American English and Kannada, so as to appreciate the influence of word order.

2. To compare the variations in intensity across frequency, in order to understand the LTASS variations for sentences of Indian English, American English and Kannada.

3. To evaluate the performance of the hearing aid when it is programmed to three settings i.e., NAL-NL1 procedure, optimized for Indian English sentences and optimized for Kannada sentences.

4. To compare the optimized gain setting for Indian English and Kannada with NAL-NL1 prescription.

5. To evaluate and compare the perceptual outcomes of the hearing aid programmed to NAL-NL1, optimized for Indian English sentences and optimized for Kannada sentences.

The data for the present study were collected from 39 ears (N=39 ears) of 27bilingual (Kannada and Indian English) individuals. The participants in the study were categorized into four groups based on the degree of their sensorineural hearing impairment (Mild, N=10; Moderate, N=10; Moderately severe, N=10; & Severe N=9).

The data on acoustical measure and real ear measures (objective and subjective) were evaluated and compared. The acoustical measure was performed for all the three languages and the real ear measures were carried out only for the two Indian languages. The details are given below.

4.1. Data from acoustical measurements:

4.1.1 Intensity variations across time (waveform) for sentences in SVO (Indian English & American English) and SOV (Kannada) languages.

4.1.2 Intensity variations across frequency (LTASS) for sentences in SVO (Indian English & American English) and SOV (Kannada) languages.

4.2. Data from real ear measurements:

4.2.1 Real ear objective measure using insertion gain measurements

4.2.2. Real ear objective measure using visible speech measures.

4.2.2.1 Intensity variations (RMS changes in dB SPL) across frequency in real ear for sentences in Indian English and Kannada.

4.2.1.2 Speech intelligibility index (SII) for sentences in Indian English and Kannada.

4.2.3 Real ear subjective measure using speech identification tests to obtain speech identification scores for sentences in Indian English and Kannada.

The data collected on acoustical and real ear measures were tabulated and subjected to statistical analysis using Statistical Package for Social Sciences (SPSS 17.0 for windows version). Descriptive statistics and analysis of variance were computed to evaluate the objectives of the study. The results are discussed under the following headings:

4.1 Acoustical measures
4.2 Real ear measures

4.1. Acoustical measures.

The data on acoustical examination of 50 sentences each in Indian English and Kannada, recorded in male and female voice; and 50 sentences in American English in male voice were subjected to analyses for the three dimensions of speech i.e., frequency, intensity and time. The acoustical measures obtained for Indian English (IE), American English (AE) and Kannada (K) are categorized and discussed under two headings:

4.1.1 Intensity variations across time (Waveform)

4.1.2 Intensity variations across frequency (LTASS)

4.1.1 Intensity variations across time (Waveform) for sentences in Indian English, American English and Kannada.

The intensity (in dB SPL) measured in each of the initial, medial and final portions of the sentence was tabulated and subjected to statistical analysis. This was done in Indian English, American English and Kannada. Descriptive statistics was used to compare the mean and standard deviation measures of the values (Table 4.1) for the English (Indian English & American English) and Kannada, for both male and female speakers.

Table 4.1.

Mean and Standard Deviation (SD) of intensity (in dB SPL) across the initial, medial and final portions of the sentence, for male and female speakers in Indian English and Kannada languages and male speaker for American English.

	Mean ± (SD) Intensity in dB SPL				
Portion of sentences (N=50)	*Indian English*		*American English*	*Kannada*	
	Male	*Female*	*Male*	*Male*	*Female*
Initial	78.71 (1.76)	78.43 (1.42)	70.44 (0.89)	78.99 (1.24)	80.93 (1.65)
Medial	76.80 (2.06)	77.12 (2.16)	64.99 (1.95)	77.30 (1.37)	79.39 (1.64)
Final	75.92 (2.37)	76.18 (2.84)	66.97 (1.37)	73.98 (1.58)	76.83 (1.79)

From Table 4.1, it can be inferred that mean intensity variation across the sentence followed a same trend for Indian Englishand Kannada. For both of these languages a falling trend in intensity across the sentence is evidenced. It can also be seen from the SD values (Table 4.1) that there were no much variations between the 50 sentences analyzed for the intensity variations across the three portions of the sentences.

This finding is consistent for both the male and female speakers. The finding of low SD for both speakers across all the portions of the sentences can be due to talker-specificity. Since the recorded samples of both languages were taken from the same speakers, such high degree of consistency in data (Table 4.1) as revealed by low SD can be expected. This study is in consensus with that by Chasin (2012b). Chasin (2012b), in his study found that in the languages which follow a SOV pattern (Hindi, Urdu, Korean, Japanese, Turkish and Iranian), the decline in intensity is relatively more to than English, which follows a SVO structure.

In order to find out the if the languages (Indian English& Kannada) are significantly different from each other, Mixed ANOVA was done with gender as across subject variable and the intensity (in dB HL) for languages (Indian English& Kannada) and portion in the sentence (initial, medial & final) as within subject variables. Post-Hoc Duncan test was done when main effect and interactions existed for gender; and Bonferroniadjusted multiple comparison test for languages and portion of sentences. The results of the analyses showed that there was an overall main effect and significant interactions between gender, languages and portions of sentence. Significant interactions were found between language and gender [F(2,96)=9.42, $p<0.01$]; and portion of sentence and gender [F(2,96)= 2.88, $p<0.05$)]. Results showed that there was a significant difference across initial, medial and final portions of the sentence [F(2,196) = 9.443, $p<0.01$)]. There was no significant difference between Indian English and Kannada.

The finding of no significant difference between the languages (Indian English& Kannada) can be attributed to the fact that the speakers (Male & Female) were bilinguals with Kannada as their first language(L1) and English as their second language(L2). This could be due to the interference of phonetic features of the native or L1 with the phonetic features of L2. In the opinion of Cheng, Robb, Gilbert,and Lerman (2001) individuals who speak English as a second language vary in their ability to produce phonetic features of English precisely. The interference of L1 with L2 production can occur at both the segmental and suprasegmental levels (Ingram &Pittam, 1997; Shen, 1990). Hence, due to the influence of the Kannada (L1, which is a SOV language) over Indian English (L2, which is a SVO language), both of these languages have shown a decline in the intensity across the sentence.

Mixed ANOVA results also showed that the intensity across sentences uttered by the male speaker was significantly different when compared to female [$F(1,98)=20.87$, $p<0.01$)]; with male speaker showing higher intensity values than female speaker at all the portions of the sentence for both the languages (Table 4.1 & Figure 4.1).

Hearing aid prescription formulae are based on LTASS of languages such as American English. Hence, recording of male American speaker of 50 IEEE sentences were analyzed to compare the variations in intensity across sentence over time between Native American English and Indian English. For the male speaker, in order to understand if significant differences existed across languages and across sentence, the data were subjected to Repeated measures ANOVA. The results showed that there was a significant overall main effect and interaction across languages (American English, Indian English& Kannada) and portion in the sentence (initial, medial & final). When interactions were observed, Bonferroni adjusted multiple pair-wise comparisons were made. The results of the analyses showed that there was a significant difference across languages (i.e., Indian English, American English& Kannada) [F(2, 98)=36.853, $p<0.01$] and across the three portions of sentence [F(2, 98)= 296.2, ($p<0.01$)].

Since, intensity across sentence of male speaker and female were significantly different, these groups were analyzed separately by using Repeated measures ANOVA. The results are depicted in the Figures 4.1 and 4.2. For male speaker, the results showed that all the three portions of the sentence were significantly different from the each other ($p<0.01$) except for the intensity at sentence medial and final portions. For female speaker, all the three portions of the sentence were significantly different from the each other ($p<0.01$).

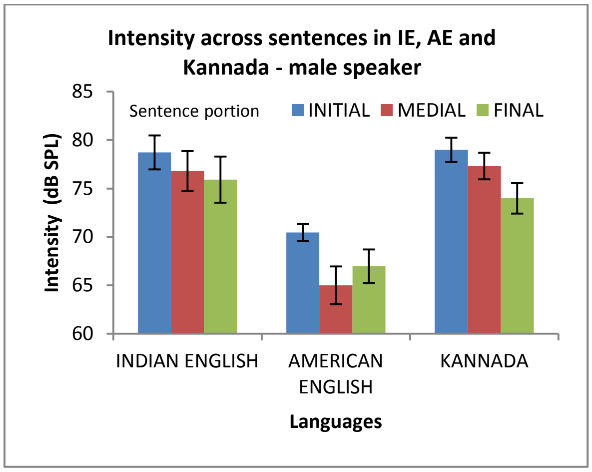


Figure 4.1. Intensity across initial, medial and final portions of sentences in IE, AEand K uttered by a male speaker.

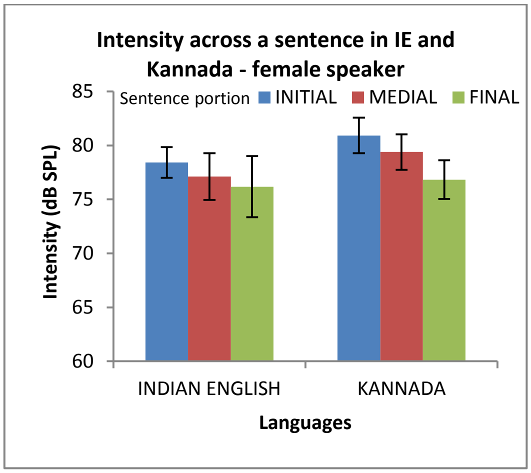


Figure 4.2. Intensity across initial, medial and final portions of sentences in IE and K uttered by a female speaker.

From the Figures 4.1 and 4.2, it is evident that though the overall pattern for Indian English and Kannada is similar (i.e., fall in intensity in the sentence final position), slight deviances such as intensity of female voice being more than male in Kannada are also observed. This can be attributed to the intra-speaker variables such as monitoring voice levels while recording the sample, characteristics of the talker, nature of the speaking task (Hodge &Gotzke, 2012) characteristics of the recording system including the distance of microphone from the mouth of the speaker, sensitivity and frequency response of microphone, the efficiency of software and sound card used for recording and factors related to the recording environment (noise levels and audio/ visual distracters). This is particularly true for the American English speaker, due to the unavailability of native American speaker, the sentences taken for the acoustic analyses of the same language were extracted from a CD which were recorded earlier. Thus, all the factors enlisted above could have played an influential role on the intensity patterns across the sentence. Inspite of such confines, it is evident from the Figure 4.1. that in American English, the influence of word order on the intensity fall at the second portion of the sentence followed by a rise at the final portion.

It can also be inferred from the Figure 4.1 and 4.2 that the native American speakers tend to produce final portion of the sentence with an higher intensity. This is in consensus with Chasin (2011) who reported that languages having SVO pattern tend to show an increase in intensity at or near the end of the sentence.

However, the same trend is not evident in Indian English. This shows that Indian speakers produce English in a way which is different from that of native American speakers, i.e., unlike native American English speakers, Indian speakers produce English with falling intensity pattern. In spite of English following the SVO pattern with inherent higher intensity in the sentence final position, not all dialects of English (as evident from the current study with Indian English) follow the same trend. The acoustical analyses of English spoken by Indian bilingual speakers revealed that Indian English does not show a raise in intensity at the sentence final position. Instead, intensity continues to drop at the sentence final portion. This shows that there is an effect of first language (Kannada) on the second language i.e., English. It would be interesting to study the variation of intensity in a sentence when a native bilingual speaker (with Indian English as L1 and Kannada as L2) utters sentences in Indian English and Kannada.

For Kannada, there was a drop noticed at the sentence final position. The reason for this is that Kannada, like most other SOV languages, usually ends with a verb. Verbs like other functional words such as prepositions, adverbs, adjectives and conjunctions are more likely to be lower in intensity at the end of utterance when compared to SVO (English) languages which tend to end with an object / noun. A similar pattern was reported by Chasin (2012) on other SOV languages such as Japanese, Korean, Urdu and Hindi.

However, a closer examination of the mean and SD values (Table 4.1) show that this decline in intensity at the final portion of the sentence is more for Kannada (a decline in mean value by 4 to 5 dB SPL at the sentence final portion) when compared to Indian English (a drop in mean value by 2 – 3 dB SPL). This trend was consistent for both male and female speakers. Thus, it can be concluded that the second language (L2 i.e., Indian English) does not completely resemble first language (L1 i.e., Kannada); on the other hand, the features of L1 might interact and change the features of L2.

4.1.2 Intensity variations across frequency (LTASS) for sentences in Indian English, American English and Kannada.

The data obtained from the analyses of LTASS measurement (using MATLAB) for 50 sentences (in each of the Indian English, & Kannada by both male and female speakers) and 50 sentences in American English were utilized for the evaluating the intensity variations across frequency (LTASS) for sentences in Indian English, American English and Kannada. All the 50 sentences in each language for each speaker were edited into a single waveform without any inter-sentence intervals. Five LTASS measurements (2 files for Indian English by one male and one female; 2 files for Kannada by one male and female and one file for American English) were made and data were tabulated.

The grand mean values of LTASS computed from 50 sentences as described above was tabulated in Table 4.2. The comparison of the mean intensity (dB SPL) values across the frequencies facilitates the understanding of the variations in the LTASS across the SOV and SVO languages.

Table 4.2.

Mean intensity (in dB SPL) across the low-, mid- and high- frequencies for the sentence recorded by male and female speakers in Indian English and Kannada and by male speaker in American English.

Frequency range	*Mean Intensity in dB SPL (N=50)* *Indian English*		*American English*	*Kannada*	
	Male	*Female*	*Male*	*Male*	*Female*
Low	59.78	58.44	57.62	60.8	58.92
Mid	49.6	48.6	53.05	61.35	53.05
High	43.45	45.43	44.8	46.03	47.83

Note: Low- (avg. 0.25, 0.5, 0.8 & 1 kHz); Mid- (avg. 1.5k, 2k & 2.5 kHz); High- (avg. 3k &4kHz)

From the Table 4.2, it can be inferred that there is a general decline in the intensity (dB SPL) from low to high frequencies. This trend is similar for both male and female speakers; and across Indian English, American English and Kannada. This finding is in consensus with abundant studies reported in literature such as Byrne et al. (1994), Cox and Moore (1988), and Wong, Ho, and Chua (2006).The shape of speech spectrum of the current study and its comparison with the findings of Byrne et al. (1994) reveals a similarity in the pattern (Figure 4.4, 4.5 and 4.6).

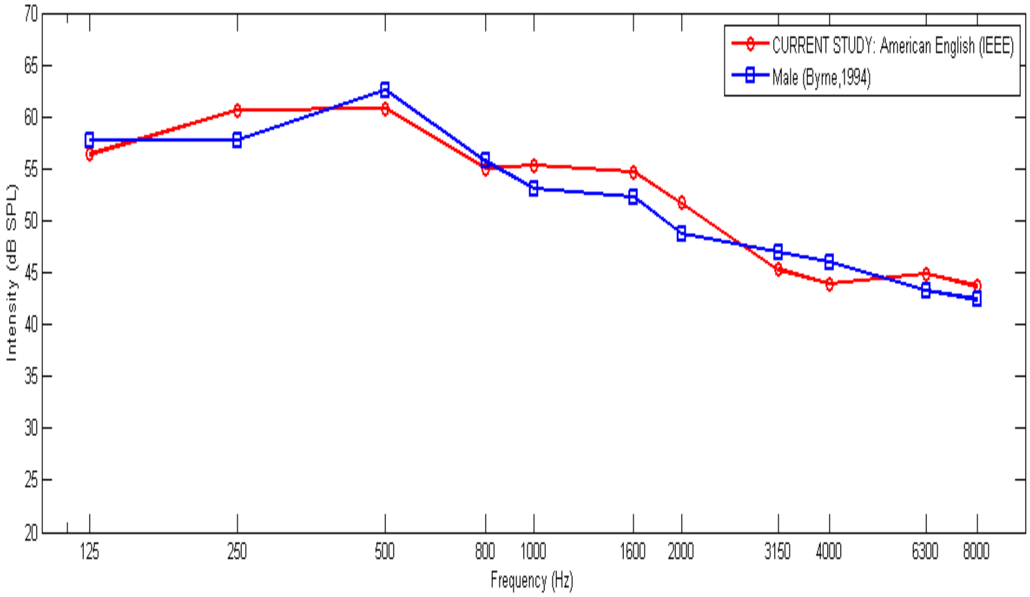


Figure 4.3.LTASS of male and female speakers in American English (current study) vs. universal LTASS (Byrne et al., 1994).

The LTASS of 50 IEEE sentence recorded by the male speaker was similar to the spectra of the universal LTASS (Byrne et al., 1994). The graph of the plot of frequency vs. intensity (Figure 4.3) revealed that there was a considerable overlap between the two curves (red- current; blue- Byrne). This result is expected because universal LTASS also includes American English (AE) as one of its component language during its derivation. Similar to the American English, a falling trend in intensity across frequency is observed for the Indian English (IE) also (Figure 4.4).

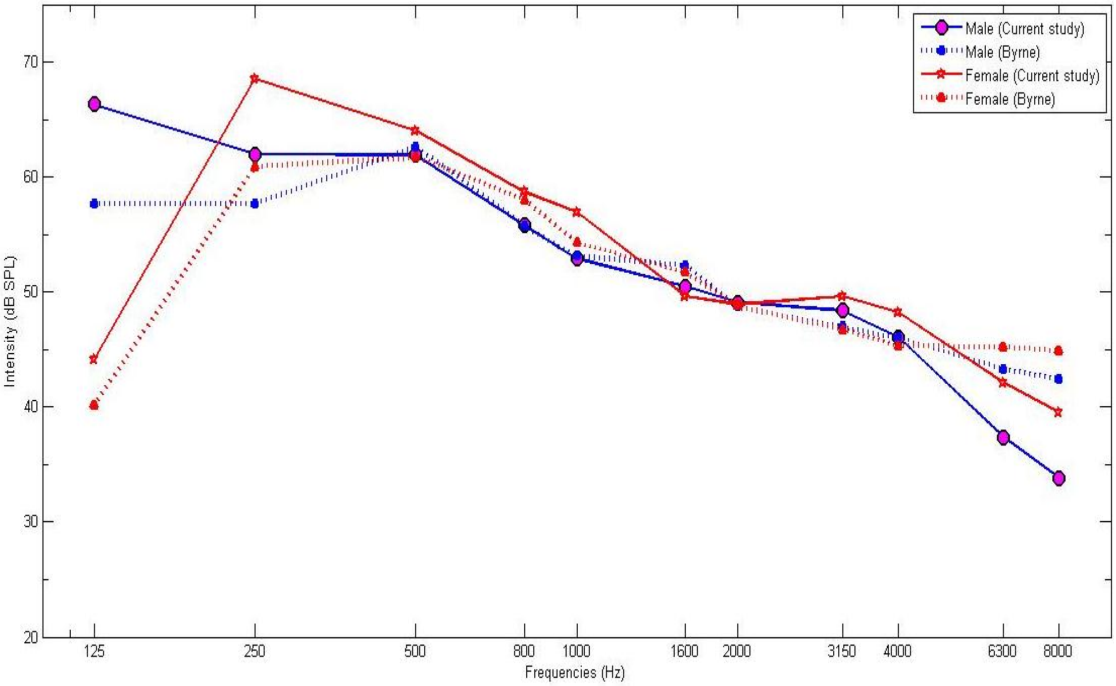


*Figure 4.4.*LTASS of male and female speakers in Indian English (current study) vs. universal LTASS (Byrne et al., 1994).

Examination of the speech spectrum of Indian English (Figure 4.4) shows that the mean intensity of the male speaker was higher than that of the female speaker, at very low frequencies (lesser than 250 Hz). On the other hand, at mid- and high- frequencies, mean intensity of females was higher than males. This finding is in consensus with that reported by Byrne et al. (1994) where in mean intensity of males for 12 internationally spoken languages was significantly greater than females at low frequencies till approximately 500 Hz. For frequencies greater than 500 Hz, the mean intensity values of males were lesser than females.

However, there was a deviation in the mean LTASS values between the Indian English and universal LTASS, in the lower frequencies. The reason could be attributed to the influence of first language (L1 - Kannada) of the speaker on the second language (L2

–Indian English). A similar finding was also reported by Ackerman et al. (2012) in Mandarin-English bilinguals. These authors observed that Mandarin-English bilinguals, while speaking English also show variations in LTASS from the native English speakers. Thus, the authors conclude that, keeping the language constant mitigates some, but not all, of the observed L1 vs. L2 differences. This finding suggests that variations in LTASS are due to contributions from both talker (speaker-specific variations) and language-specific as well.

The above discussed languages, i.e., American English and Indian English follow an SOV order. However, most Indian languages (like Kannada) follow an SVO pattern. Since, Kannada varies from English in terms of acoustical, morphological, syntactical and supra-segmental domains and since LTASS varies with language spoken by an individual, a comparison was made between Kannada and universal LTASS. The results are depicted in the Figure 4.5.

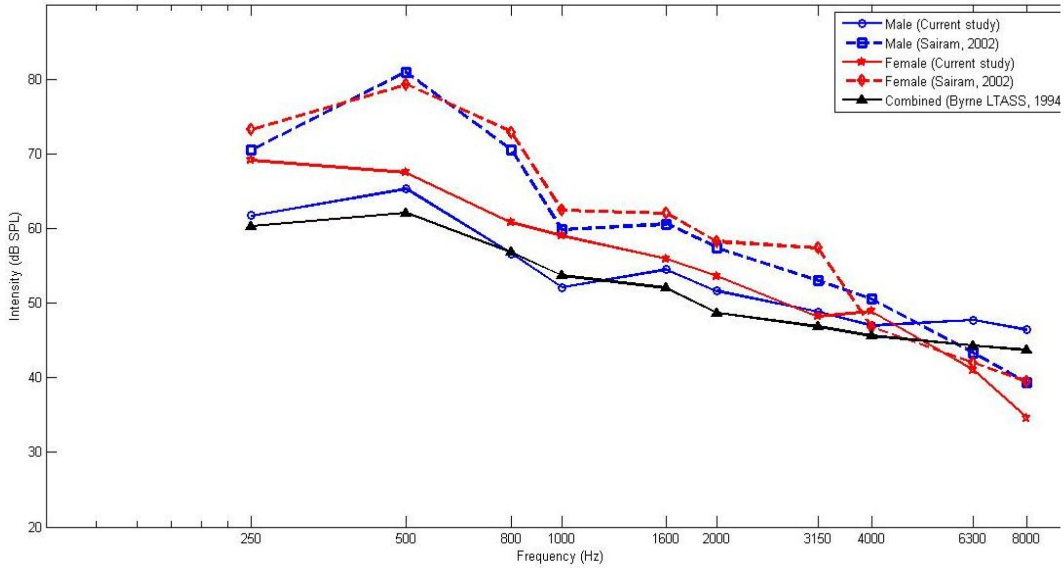


*Figure 4.5.*LTASS of male and female speakers in Kannada (current study) vs. Kannada (Sairam & Manjula, 2002) vs. universal LTASS (Byrne et al., 1994).

As is evident from Figure 4.5, the LTASS of Kannada language (SOV) also follows a similar trend i.e., decrease in intensity with an increase in the frequency. The current study thus supports the results of several studies in Indian languages such as Hindi (Rupela&Manjula, 2002), Kannada (Sairam & Manjula, 2002) and Malayalam (Samuel & Yathiraj, 2002). All of these studies found that LTASS of the Indian languages also follow the same trend like universal LTASS.

From the Figure 4.5 and Table 4.2, it can also be inferred that, LTASS of Kannada was higher than universal LTASS/English by 10-12 dB SPL for low frequencies (lesser than 1 kHz); 8-9 dB SPL for mid frequencies (1 to 3 kHz); and around 2-3 dB SPL at frequencies (greater than 4 kHz). This finding also supports the study by Sairam and Manjula (2002), who measured the LTASS of Kannada using a standardized passage (story). They reported that LTASS (mean values) of Kannada was higher than English on an average by 8.5 dB HL in low frequencies (lesser than 1 kHz), 7.33 dB HL in mid frequencies (1 kHz - 3 kHz) and 2.25 dB HL at high frequency (greater than 4 kHz).

It is also worth noting from the Figure 4.5 that female speaker was on an average 5 dB SPL more than male at low frequencies (lesser than500 Hz). But this difference reduces gradually at mid frequencies (1-3 kHz) and becomes almost nullified after 4 kHz. This finding is in accordance with Sairam and Manjula (2002) using a Kannada passage, found that LTASS curves of both male and female speakers were not only similar in their spectral shape but also considerable overlap was seen between them throughout all the measured frequency range. On other hand, Noh and Lee (2012a), found that in Korean language (which also follows a SOV structure), intensity of male was greater than female lower at low frequencies, but higher than at 630, 800, 1,600, 5,000and 10,000 Hz. These conflicting reports could be due to influence of speaker-related, procedural-related and recording-related factors.

4.2. Real ear measures.

The data on real measurements included three objective data (IG obtained from IG measurement, LTASS and SII obtained from visible speech measurement) and behavioral/ subjective data i.e., speech identification scores for sentences. Objective data were obtained for hearing aid programmed and verified through insertion gain measurements for NAL-NL1 prescriptive formula, optimized for sentences in Indian English and optimized for sentences in Kannada. ANSI digi speech was used for IG measures, female voice was used for both the visible speech measures and behavioural perceptual measures. The results of statistical analyses of the real ear data will be discussed under the following headings:

4.2.1 Real ear objective measure using insertion gain measures.

4.2.2 Real ear objective measure using visible speech measures.

4.2.3 Real ear subjective measure using speech identification tests.

4.2.1 Real ear objective measure using insertion gain measurements.

To evaluate and compare the difference in the hearing aid set to NAL-NL1 prescription formula vs. the two optimized settings, the data obtained from insertion gain measurements were used. This provided the information on the difference in the gain when hearing aid is set to optimized setting, as compared to the gain prescribed by NAL-NL1.The mean and SD of IG obtained through the descriptive statistics for the three hearing aid set to three conditions i.e., NAL-NL, optimized to Indian English and Kannada are shown in Table 4.3.

Table 4.3.

Overall mean and Standard Deviation (SD) of IG (in dB) across low-, mid-, high-frequencies for Indian English and Kannada with hearing aidset to NAL-NL1 and optimized settings.

Frequency range	*Mean ± (SD) of IG in dB*		
	NAL-NL1	*Optimized*	
(N=39)		*Indian English*	*Kannada*
Low	21.49	28.02	25.27
	(8.18)	(7.73)	(8.06)
Mid	27.27	32.79	30.48
	(7.49)	(7.99)	(8.29)
High	21.39	26.89	25.44
	(7.99)	(8.73)	(8.63)

Note: Low- (avg. 0.2, 0.5, 0.8 & 1 k Hz); Mid- (avg. 1.5 k, 2 k & 2.5 k Hz); High- (avg. 3 k & 4 k Hz).

From the Table 4.3, it is evident that gain required for Indian English (IE) and Kannada (K) are more than the gain prescribed by NAL-NL1 formula. It can also be noted thatinsertion gain ofhearing aid set to optimized Kannada setting is lower than the optimized Indian English setting at the low- and mid- frequencies. This finding can be attributed to the variation in the language structure between Indian English and Kannada. Kannada is a mora-timed language (Savithri et al., 2007). The minimal unit in Kannada is a mora (which is like a semi-syllable). Due to the inherent property of semi-syllabic nature, words in Kannada usually tend to end with a vowel at the end. But, English is a typical example for a language with stress-timed rhythm (Abercrombie, 1964). It ends with a consonant. Hence, due to presence of vowels in every minimal unit of the Kannada and since vowels have frequency composition in the low- and mid- frequencies, Kannada requires less gain at these frequencies when compared to Indian English.

Furthermore, Mixed ANOVA was performed with degree of hearing loss as the across subject factor, frequencies (low, mid and high) and conditions (NAL NL-1 setting, optimized settings for English and optimized settings for Kannada) as within subject factors. This was done to find out if there was any main effect and if there were any significant interactions. Results revealed that there was significant interactions between the degree of hearing loss with frequency [F(6,70) = 5.16,$p<0.01$] and conditions [F(6,70) = 3.56, $p<0.01$]. Hence, each condition (NAL-NL1, optimized English & optimized Kannada) was studied separatelyfor each degree of hearing loss using Repeatedmeasures ANOVA.

The results of Repeated measures ANOVA showed that the IG of optimized settings for both Indian English and Kannada were significantly different from NAL-NL. Bonferroniadjusted multiple pair-wise comparison was done for finding out if there is significant difference between IG of hearing aid set to NAL-NL1 and optimized English setting.This is depicted in the Table 4.4 and Figure 4.6.

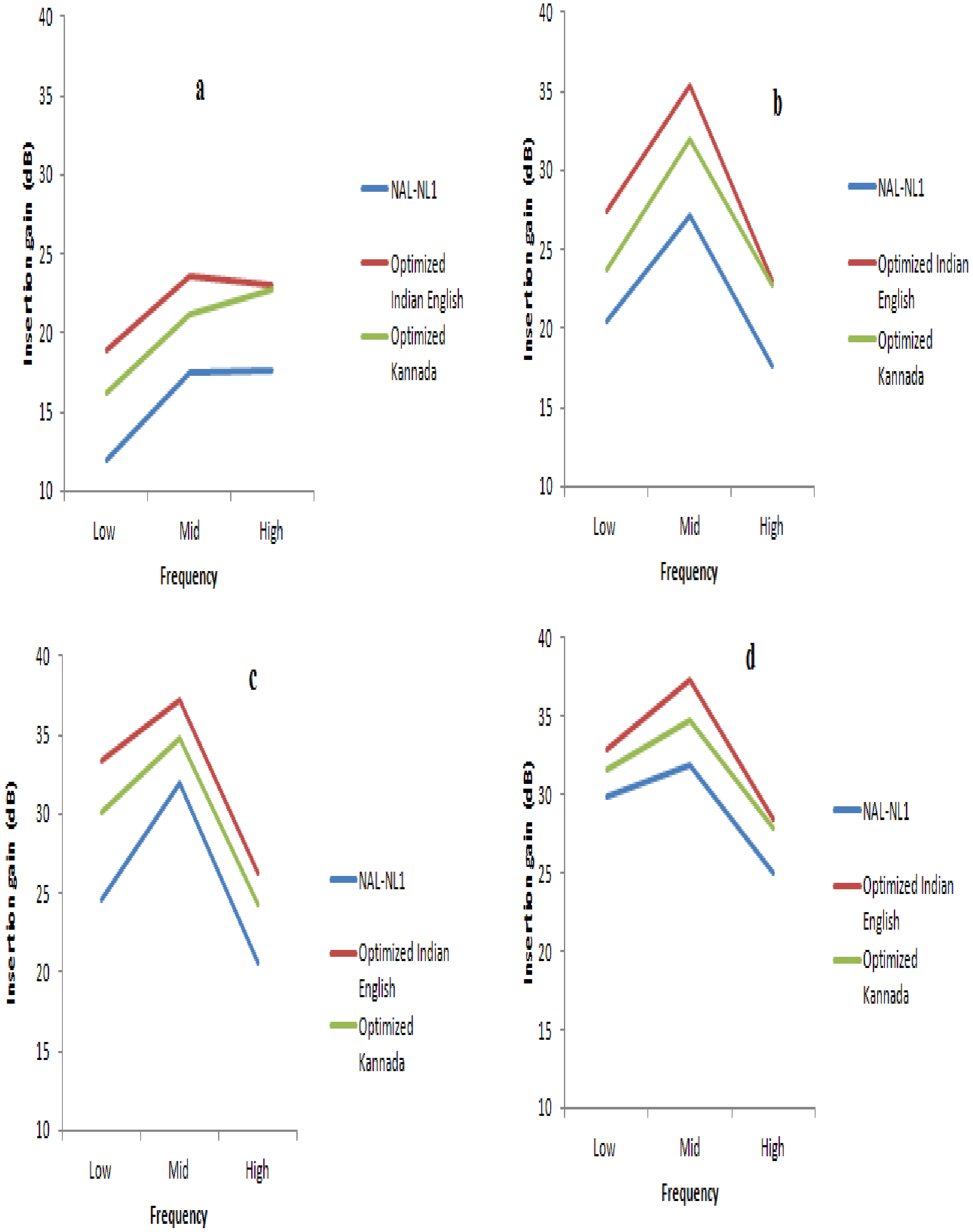


Figure 4.6 IG (in dB) of hearing aid set to NAL-NL1, optimized Indian English and optimized Kannada settings for *(a)* Mild SNHL *(b)* Moderate SNHL *(c)* Moderately severe SNHLand *(d)* Severe SNHL.

Table 4.4.

Significance of difference (p)in IG mean scores between NAL-NL1 vs. optimized English and NAL-NL1 vs. optimized Kannada across 4 degrees of hearing loss.

Frequencies	*Conditions*	*Mild*	*Moderate*	*Moderately severe*	*Severe*
Low	NAL-NL1vs. optimized Indian English	**	**	**	*
	NAL-NL1vs. optimized Kannada	**	*	**	*
Mid	NAL-NL1vs. optimized Indian English	**	**	*	*
	NAL-NL1vs. optimized Kannada	*	*	*NS*	*
High	NAL-NL1vs. optimized Indian English	**	**	**	*
	NAL-NL1vs. optimized Kannada	**	*	*	*

Note: *Low- (avg. 0.2, 0.5, 0.8 & 1 kHz); Mid- (avg. 1.5 k, 2 k & 2.5 kHz); High- (avg. 3 k & 4 kHz) frequencies.*

Note: Levels of significance (*p*): **- $p<0.01$; * - $p<0.05$; NS- no significant difference

From the Figure 4.6 and the Table 4.4, it is clear that gain required for Indian English is comparatively more than the gain requirement for Kannada, especially in the low- and mid- frequencies. This finding can be attributed to the difference in the frequency of occurrence of phonemes in the language. In Kannada, the frequency of occurrence of vowels is more as compared to the consonants (Ranganatha, 1982). Since, the vowels are more confined to the low- and mid- frequencies, the amount of gain required for the same is relatively lesser than the higher frequencies. This is especially true for Kannada. On the other hand, English has predominantly high frequency phonemes. Hence, the gain requirement at the low frequency and mid frequency compared to Kannada is high.

It is also found in the study that there is a decline in the IG at the high frequency relative to mid and low frequencies. This finding can be because in individuals with hearing impairment are known to have usually poorerthresholds at high frequencies. The unaided thresholds at high frequency were poorer for the participants in the study. Since IG is the difference between real ear aided and unaided gain and because the participants had poorer unaided high frequency thresholds, the relative difference between aided and unaided thresholds would have reduced at high frequency. Thus, the finding of lower values of IG at high frequency can be explained. But in mild hearing loss, this trend i.e., decline in IG at high frequency, was not observed. This is because the participants in the study at the mild hearing loss, unlike the other degrees of hearing loss (Moderate, moderately-severe & severe) did not have very poor thresholds at the high frequencies compared to low and mid frequencies.

In addition to the above, hearing aid chosen in the study provides lower gain for the high frequencies as compared to low- and mid- frequencies. Thus, either of these of these factors or a combined effect of both would have limited the hearing aid IG at high frequencies.

From, the above discussion it is clear that, NAL-NL1prescriptive formula is not adequate for the languages used in the current study. Indian English requires more gain than Kannada, especially at low and mid frequencies.

4.2.2 Real ear objective measures using visible speech measures.

To evaluate and compare the hearing aid benefit derived from the hearing aid programmed and verified for NAL-NL1 prescription formula and the two optimized settings, the recorded sentences in Indian English (IE) and Kannada were played through the audiometric loudspeaker located at 45^0Azimuth kept at a distance of 1 meter from the participant. After the probe microphone measurements, the visible speech measures were obtained using Fonix 7000 real ear analyzer. This provided the information on the intensity (dB SPL) across frequency in the ear canal in the aided condition. This was tabulated along with the aided SII for the hearing aid programmed and verified with NAL-NL1 prescription formula and the two optimized settings. The data were collected from the participants belonging to 4 degrees of SNHL (mild, moderate, moderately severe and severe). The results of analyses of the objective data measured in the real ear will be discussed under the following headings.

4.2.2.1 Intensity variations (RMS changes in dB SPL) across frequency in real ear for sentences in Indian English and Kannada.

4.2.2.2 Speech intelligibility index (SII) for sentences in Indian English and Kannada.

4.2.2.1 Intensity variations (RMS changes in dB SPL) across frequency for sentences in Indian English and Kannada, in the real ear.

The sentences routed through the loudspeaker of the audiometer, placed at an angle 45^0 kept at a distance of 1 meterand the SPL across frequency in the ear canal of participant was measured. This was done when the participant was wearing the hearing aid in three settings, i.e., programmed and verified to NAL-NL1 setting, optimized Indian English (IE) and optimized Kannada sentences. This yielded aided LTASS for IE and Kannada. The mean and SD of the same obtained through the descriptive statistics are shown in Table 4.5.

Table4.5.

Mean and Standard Deviation (SD) of aided LTASS (in dB SPL) across low-, mid-, high-frequencies for Indian English and Kannada with hearing aidset to NAL-NL1 and optimized settings.

Frequency range	*Mean ± (SD) of intensity in dB SPL*			
	NAL-NL1		*Optimized*	
(N=39)	*Indian English*	*Kannada*	*Indian English*	*Kannada*
Low	41.64 (13.19)	42.34 (13.92)	52.38 (14.25)	52.41 (14.39)
Mid	43.63 (13.31)	45.87 (14.04)	53.77 (14.16)	53.35 (15.46)
High	41.25 (8.96)	42.65 (9.51)	50.28 (10.09)	50.64 (9.71)

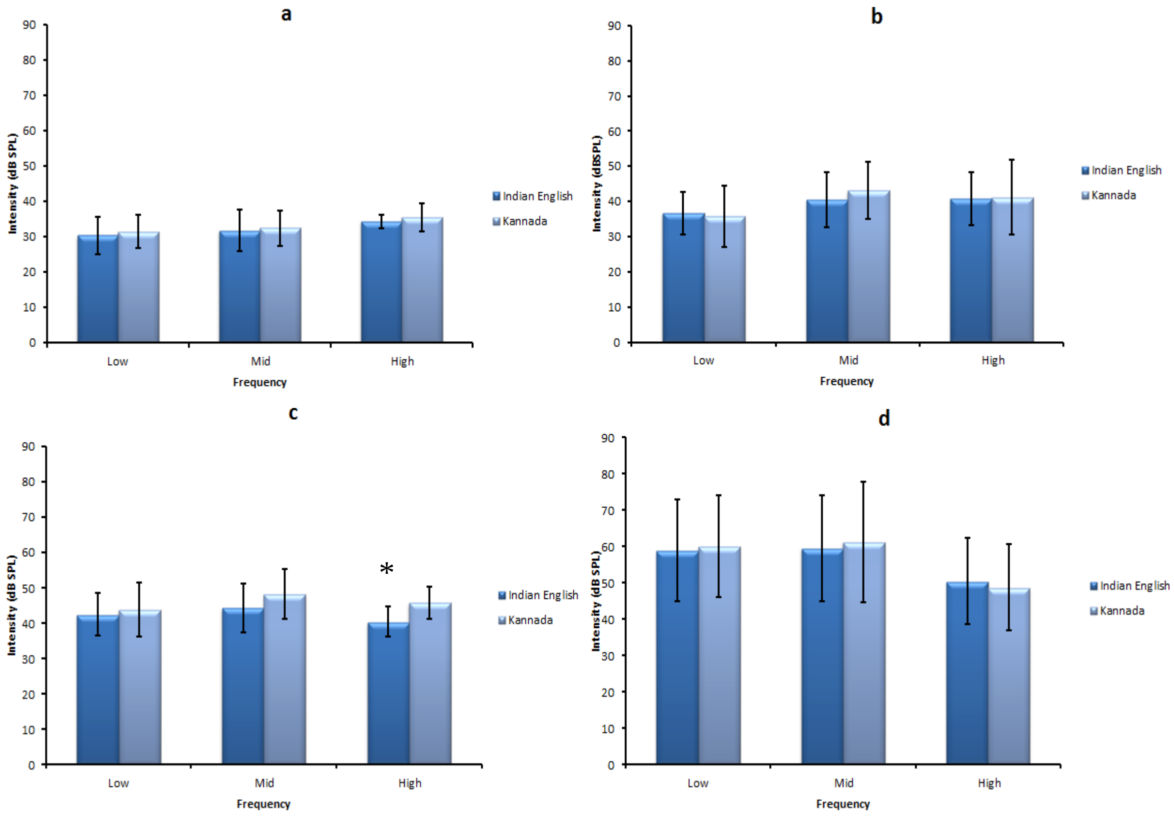
Note: Low- (avg. 0.2,0.5,0.8 & 1kHz); Mid- (avg. 1.5k, 2k & 2.5 kHz); High- (avg. 3 k & 4 kHz).

It can be inferred from the Table 4.5 that for NAL-NL1 setting, Kannada has higher LTASS values compared to Indian English. This finding was seen for all the frequencies. However, such a trend was not seen in the two optimized setting, where there is no difference in mean LTASS the two languages. There was a low difference (approximately 2 dB SPL) in the mean values between Indian English and Kannada in NAL-NL1. This finding can be due to wide range of threshold variations among the participants in the study, leading to the nullification of the effect of language on LTASS (which was otherwise apparent in acoustic LTASS). This is particularly an issue of concern since the current study considered participants belonging to four degrees of hearing loss, ranging from mild to severe.

In addition, from Table 4.5, it can also be noted that optimized LTASS values for both Indian and Kannada are higher than the LTASS values obtained through hearing aid programmed to NAL-NL1 setting. This finding reveals that hearing aid users speaking and hearing to languages which have a drop in intensity at the end of the sentence (i.e., for Indian English and Kannada, as revealed through acoustic analyses) require more gain than that prescribed by NAL-NL1. These results are similar to the findings of Achaiah and Narne (2011). They reported that Kannada native speakers preferred an additional gain of about 10 dB SPL compared to NAL-NL1, for sound input of 45 dB HL.

To find out if there are differences in the aided LTASS for Indian English and Kannada, with hearing aid set to NAL-NL1 and optimized gain settings across four different degrees of SNHL, the data were subjected to Mixed ANOVA. The results revealed that, there were significant interactions between the degree of hearing loss and within subject factors such as frequency range [$F(6,70) = 10.77$, $p < 0.01$] and hearing aid settings [F(6,70) = 10.88, *p* < 0.01]. Post-Hoc Duncan revealed that mild hearing impaired individual were different from moderate, moderately severe, who in turn were different from severe hearing loss.

As significant interactions existed between the degree of hearing loss with frequency and hearing aid settings, to know the differences between Indian English and Kannada, each degree of hearing loss was analyzed separately for each hearing aid setting (NAL-NL1 & optimized settings) using paired sample t-test. The results of the data analyses are shown in Figure 4.7.



Note: Levels of significance (*p*): **- *p*<0.01; * - *p*<0.05

*Figure 4.7*LTASS of Indian English (IE) and Kannada with hearing aid set to NAL-NL1 for *(a)* mild SNHL *(b)* Moderate SNHL *(c)* Moderately severe SNHLand *(d)* Severe SNHL.

From the Figure 4.7 it is clear that, the LTASS of Indian English was not significantly (p>0.05) different from Kannada. This finding was similar to all degrees of hearing loss except high frequency of moderately severe hearing impaired group, in which both the languages are found to vary significantly [$t(9) = 0.162, p<0.05$) This finding can be attributed to the fact that for most of the moderately severe SNHL participants, there is a wide range of the variance in the thresholds. Those participants having thresholds falling at the lower range of severe degree (56-60 dB HL) would relatively have lesser hearing loss desensitization (HLD) issues as compared to those who fall in the upper range (61-70 dBHL) of the moderately severe category (Studebaker, Sherbecoe, McDaniel, & Gray, 1997).

For the optimized setting of Indian English and Kannada, paired t-test results revealed that there was no significant difference ($p > 0.05$) between the aided LTASS of Indian English and Kannada for low-, mid- and high-frequencies for all the degrees of hearing loss (Figure 4.8).

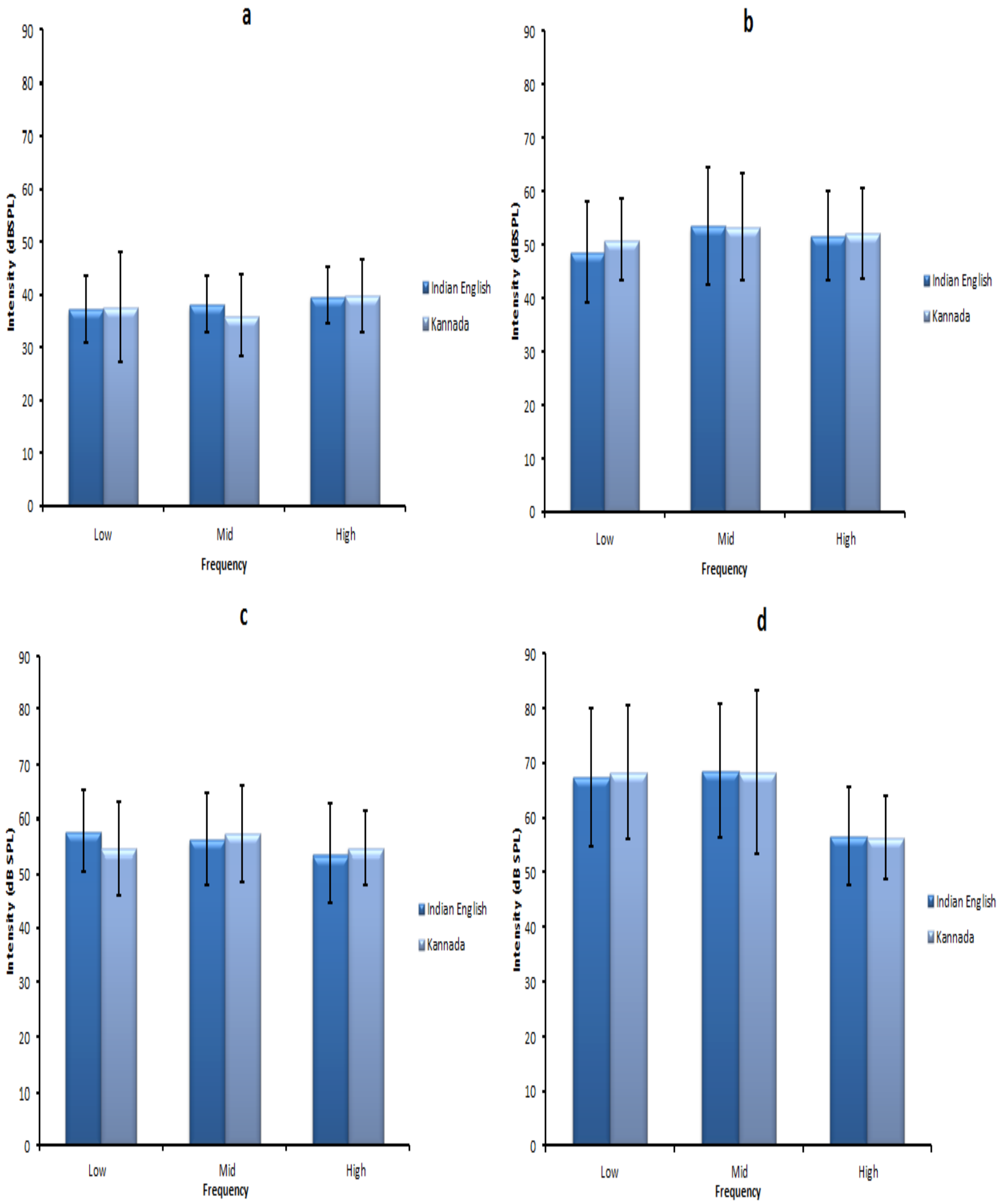


*Figure 4.8*LTASS of Indian English (IE) and Kannada with hearing aid set to NAL-NL1 for *(a)* mild SNHL *(b)* Moderate SNHL *(c)* Moderately severe SNHLand *(d)* Severe SNHL.

From the Figure 4.8, it is evident that the optimized settings was providing appropriate gain for each of the languages i.e., the hearing aid was fine-tuned to get maximal benefit. This is further substantiated by the finding that there was no significant difference in LTASS measured for both the languages. Thus, it can be concluded that benefit derived from the hearing aid will be optimal when it is fine-tuned based on the visible speech measures. This finding is supportive of the study by Nikhil and Manjula (2009) who found that fine-tuning the hearing aid through visible speech measures is indeed a more valid method of hearing aid prescription as it adds on more objectivity to the prescription procedure.

4.2.2.2 Speech intelligibility index (SII) for sentences in Indian English and Kannada.

Similar to the data obtained for the aided LTASS as discussed in 4.2.2.1, Visible speech measures using the Fonix real ear module is employed in the measurement of SII as well. The SII measured through this procedure accounts for the audibility issues as it considers correction factors such as hearing loss desensitation factor (HLD) and speech level distortion factor (SLD). Fonix real ear module gives the SII as an absolute value ranging from 1 to 100. Similar to Aided LTASS, aided SII data were tabulated from the participants belonging to four degrees of SNHL (mild, moderate, moderately severe and severe). The data thus obtained were subjected to the statistical analyses. The descriptive statistics - mean and standard deviation - of the aided SII for Indian English and Kannada with hearing aid set for NAL-NL1 and optimized setting is plotted in the Figure 4.9.

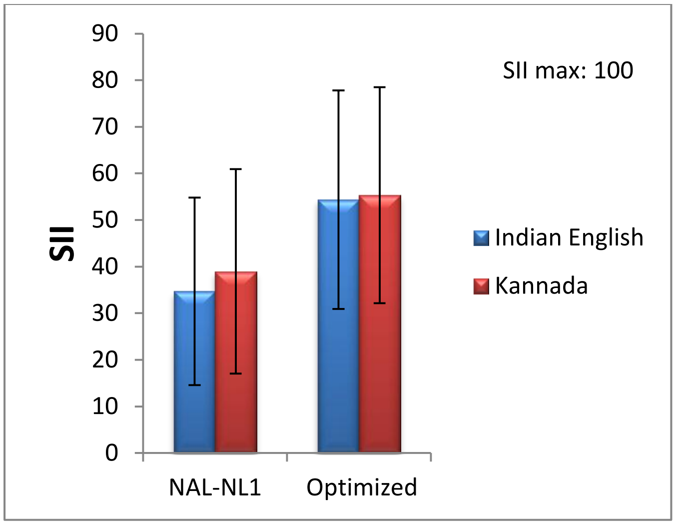
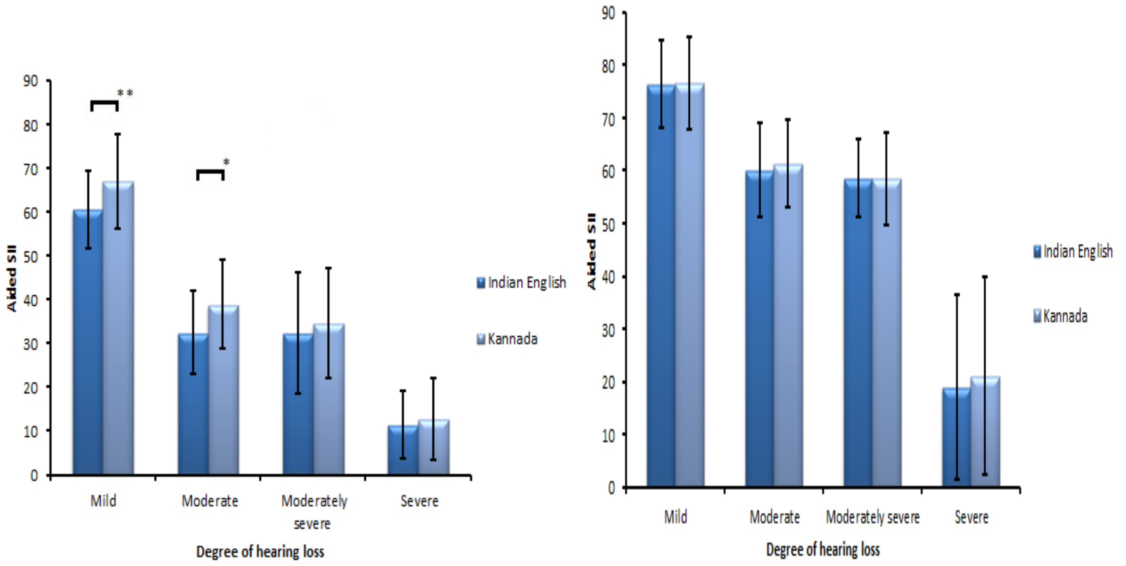


*Figure 4.9*AidedSII of Indian English (IE) and Kannada with hearing aid set to (a) NAL-NL1 and (b) optimized.

From the Figure 4.9, it can be inferred that the aided SII of Kannada setting is higher than SII of Indian English when hearing aid is programmed for NAL-NL1. The SII data were subjected to the Mixed ANOVA. The results of Mixed ANOVA revealed significant interactions of degree of hearing loss with hearing aid settings[F(2,70) = 23.862, $p < 0.001$). Hence, the two hearing aid settings i.e., NAL-NL1 and optimized settings were studied separately to find if there is a difference between the languages tested in the respective setting,using Repeated measure ANOVA. The results are depicted in the Figure 4.10 (a) & Figure 4.10 (b).



Note: Levels of significance (*p*): **- $p<0.01$; * - $p<0.05$SII range:0-100

*Figure 4.10*AidedSII of Indian English (IE) and Kannada across 4 degrees of hearing loss with hearing aid set to (a) NAL-NL1 and (b) optimized.

From the Figure 4.10 (a), it is clear that the SII for Kannada language is significantly more than Indian English only for the mildSNHL[F(1,9) = 57.18, $p < 0.01$) and moderate SNHL [F(1,9) = 7.31, $p < 0.05$) group. It is also worthy to note that the significant difference between the two languages decreases with the increase in degree of hearing loss. This could be attributed to the fact that SII accounts for ‘effective audibility’ rather than absolute audibility. For, derivation of SII additional factors related to hearing impairment i.e., HLD and SLD are also utilized. Thus with the increase in the degree of hearing loss, it can be expected that both of these factors will come into play. Thus, SII as a measure for speech intelligibility at higher degrees of hearing loss is questionable (Scollie, 2008; McCreery& Stelmachowicz, 2011) unless the factors are well accounted using proper transfer functions.

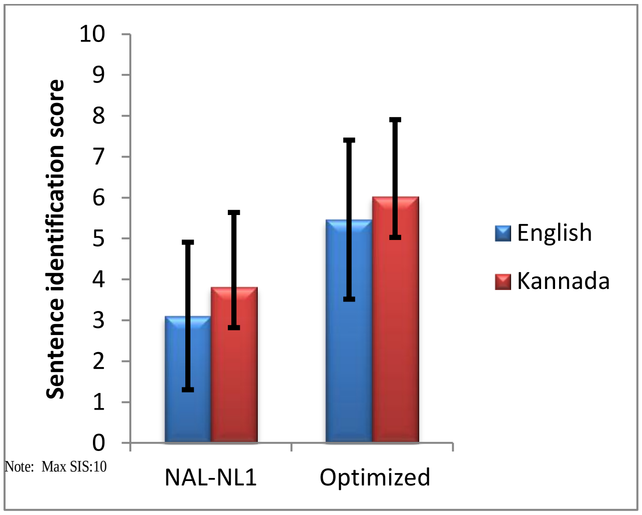
Figures 4.10 (b), for the optimized setting, there was no significant difference (*p > 0.05)* between Kannada and Indian English. This finding as discussed earlier, can be attributed to the mechanics of fine tuning the hearing aid for the realization of optimal benefits derived from it.

Another interesting observation which can account for the variability in the SII is the age of the participants in the study. The participants selection criteria though restricted to the age range of 55 years, most participants in the study were above the age of 45 years. Investigations on the effect of aging on hearing sensitivity as reported by National Institute on Deafness and Other Communication Disorders (NIDCD) (2012), reveals that decrements in hearing sensitivity can be evident from the age of 45 years. But, SII (as used in the Fonix real ear module software) does not take the age related changes into account (Fonix operator's manual, 2010; &Scollie, 2008). Changes in the auditory system due to aging, if accounted will make the measure of SII more sensitive. Thus, in the current study, the age of the participants, the insensitivity of SII as a tool for accounting the age related changes in auditory physiology or combinations of these factors could also have been a factor which could have affected the outcome of the study.

4.2.3 Real ear subjective measures using speech identification tests.

Speech identification scores for sentences in Indian English and Kannada.

Objective method gives only the intensity of the signal (SPL) in the ear canal. It does not account for the final intelligibility of the signal, which depends on the changes in the perceptual domain. In order to overcome the limitationsof objective method and to understand the correlation between objective findings and perceptual measures, behavioural speech identification scores for sentences (SIS) was measured. The data obtained were subjected to descriptive analyses, Mixed ANOVA and paired samples t-test. The mean and standard deviation of SIS are as plotted in the Figure 4.11.

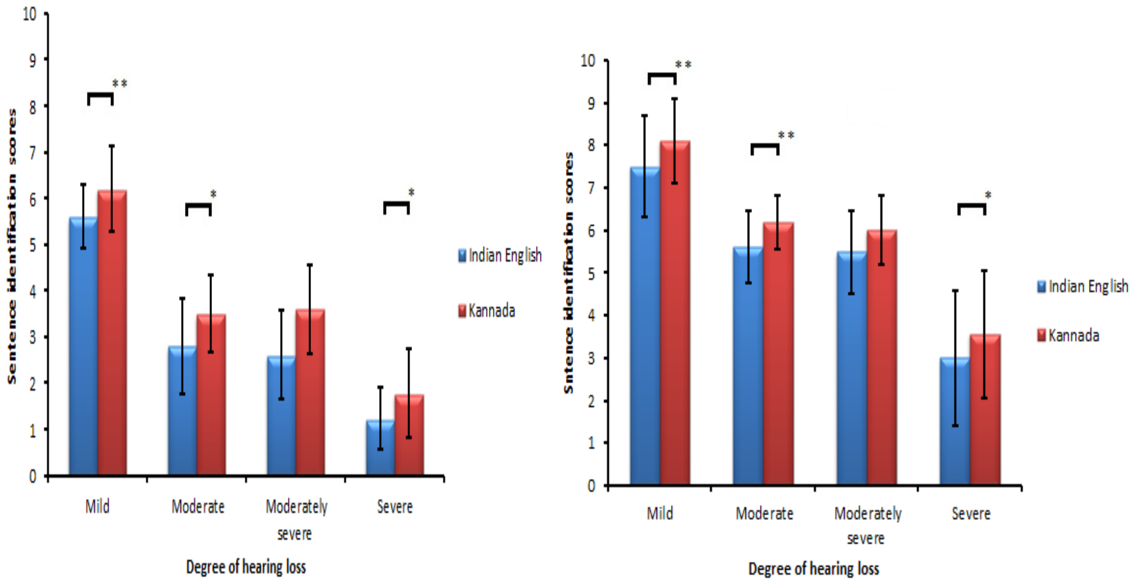


Note: Max SIS:10

*Figure 4.11*Sentence identification scores (Max = 10) for Indian English (IE) and Kannada with hearing aid set to NAL-NL1 and optimized setting.

From the Figure 4.11, it can be inferred that though not significant (*p* >0.05), the participants in the study had higher SIS scores for Kannada sentences as compared to English sentences. This could be related to the proficiency of the first language, the frequency of the exposure of the same or the combination of these factors.

The results of Mixed ANOVA revealed significant interactions of degree of hearing loss with the hearing aid settings [F(6,70) = 12.93, $p < 0.01$]. Hence, the two languages were studied separately for the two hearing aid settings i.e., NAL-NL1 and optimized settings. The results are depicted in the Figure 4.12 (a) & Figure 4.12 (b).



NOTE: Maximum SIS: 10; Levels of significance (p): ** - $p<0.01$; *$p<0.05$; SII range:0-100

*Figure 4.12*Sentence identification scores Indian English (IE) and Kannada with hearing aid set to (a) NAL-NL1 and (b) optimized setting.

From the Figure 4.12 (a) and (b), similar to the findings of SII, subjects in each degree of hearing loss performed slightly better in Kannada than in English, for both hearing aid programmed to NAL-NL1 and optimized setting. This again could be related to the exposure and duration and/or frequency of use of English language in day-to-day basis could have been less in these subjects as compared to Kannada. Although in the study, the bilingual proficiency was made equivalent through the administration of the International Second Language Proficiency Rating Scale (ISLPRS), the factors related to the duration of use of English language in day to day basis and nature of work were controlled. This throws light on the importance of controlling the occupation and the nature of work of the participant, especially so in the bilingual study such as the current one.

To summarize the results, the acoustical and objective visible speech measures real ear measures show that small degree of variability exists in aided LTASS measures between Indian English and Kannada. With respect to hearing aid fitting, this small variance can be overcome using the manual or automatic volume control settings, which can prove to be effective in coping up with subtle but yet significant differences in the gain requirement for bilingual hearing aid users.

However, manipulation of the volume control settings affects gain in all the frequencies. It is very important at this juncture to note the importance of IG measurements in the validating the hearing aid gain. Findings of the current study show that, both Indian English and Kannada required more gain than what is prescribed in accordance with NAL-NL1. Though both languages required more gain than NAL-NL1, the amount of gain required for Indian English is relatively more than Kannada, especially in low and mid frequencies. Hence, manipulation of the volume control can prove to be useful for low- or mid- frequencies, but increase of gain at the high might have deleterious effects on speech intelligibility. So, the option of volume control as an effective option to overcome the language related audibility issues becomes questionable.

The current study throws light on to the importance of factthat the clinicians need to have a whole picture of the auditory needs of the individual before prescribing a hearing aid. It is not only important to have a theoretical knowledge of the objective measures available for hearing aid gain verification, but also it is important for the clinicians to correlate the different measures which are put to use.

In addition to the above, it is not adequate just for a clinician to have a good insight into hearing loss related aspects of the bilingual hearing aid user, but also to have in depth knowledge about the issues that can affect the day-to-day performance of such individuals speaking and listening languages which differ in their basic structure (acoustical, segmentaland suprasegmental). Suchminute language related aspects and its relevance should not be ignored, since these insights shall prove to be of vital importance in all the four stages i.e., hearing aid selection, prescription, verification and validation for bilingual individuals with hearing impairment.

An audiologist should thus be aware of the language related aspects while setting the gain of the hearing aid. This in turn will bring about more satisfaction among the bilingual hearing aid users.

CHAPTER 5

SUMMARYAND CONCLUSIONS

The aim of the present study was to investigate whether a hearing aid needs to be programmed differently for languages that use either SVO (Indian English) or SOV (Kannada) patterns in a sentence. The specific objectives were

1. To compare the variations in intensity across time in sentences of Indian English, American English and Kannada, so as to appreciate the influence of word order.

2. To compare the variations in intensity across frequency in sentences of Indian English, American English and Kannada, in order to understand the long-term average speech spectrum.

3. To evaluate the performance of the hearing aid with hearing aid programmed to three settings, i.e., NAL-NL1 procedure, optimized for Indian English sentencesand optimized for Kannada sentences.

4. To compare the settings optimized for Indian English and Kannada with NAL-NL1 prescription.

5. To evaluate and compare the perceptual outcomes of the hearing aid programmed to NAL-NL1, optimized for Indian English and optimized for Kannada.

The data for the present study were collected from 39 ears (N=39 ears) of bilingual individuals having Kannada as their first language and English as their second language. All the participants had sensorineural hearing loss (SNHL) with the degree of loss ranging from mild to severe.

The data on the following acoustical measures and real ear measures (objective and subjective) were collected, tabulated and analyzed.

I. Data from acoustical measurements:

1. Intensity variations across time (waveform) for sentences in SVO (Indian English & American English) and SOV (Kannada) languages.
2. Intensity variations across frequency (LTASS) for sentences in SVO (Indian English & American English) and SOV (Kannada) languages.

II. Data from real ear measurements:

1. Real ear objective measures using insertion gain measures.

   Insertion gain variations for NAL-NL1, optimized Indian English and Kannada.

2. Real ear objective measures using visible speech measures.
   a. Intensity variations (RMS changes in dB SPL) across frequency in real ear for sentences in Indian English and Kannada.
   b. Speech intelligibility index (SII) for sentences in Indian English and Kannada.

3. Real ear subjective measures using speech identification tests.

   Behavioral sentence identification scores for sentences in Indian English and Kannada.

The data collected were tabulated and subjected to statistical analysis using Statistical Package for Social Sciences (SPSS 17.0 for windows version). Descriptive statistics and analysis of variance were computed to evaluate the objectives of the study. To investigate the presence of interaction effect and main effect, for the presence of significant differences between the languages (Indian English and Kannada) and frequencies (low-, mid-, high- and average), gender (acoustical measurements) or four degrees of hearing loss (real ear measurements), Mixed ANOVA was carried out. Bonferroni adjusted multiple pair-wise comparison was carried out to check for the presence significant differences between the pairs of conditions (NAL-NL1, optimized settings) or languages (Indian English& Kannada) if indicated.

I. Comparison of the intensity variations across time and frequencies for sentences in SVO (Indian English & American English) and SOV (Kannada) languages:

1. Intensity vs. Time (amplitude envelope)

Intensity (in dB SPL) was measured over time in 50 sentences in each of the three languages using ‘PRAAT’ software. On comparison of the mean values intensity variations across time (waveform) for sentences in SVO (Indian English & American English) and SOV (Kannada) languages, it was found that the American English was significantly different from Indian English and Kannada ($p<0.01$). Findings revealed that in American English, there was a decrease in the intensity in the middle portion of sentence, followed by an increase in intensity at the final portion. This trend was not seen for Indian English and Kannada, wherein there was a falling trend in the intensity across sentence in both of these languages. This difference is attributed to the influence of L1 over the L2.

2. Intensity vs. Frequency (spectrum envelope)

Intensity (in dB SPL) across frequency was measured in 50 sentences in each of the three languages using ‘MATLAB’software. On comparison of mean values of LTASS for American English, Indian English and Kannada, it was noted that there was a similar pattern of the spectral shape for all the three languages i.e., an increase in intensity at low frequency, followed by a fall with an increase in intensity. There was an overlap of LTASS of American English with the universal long-term average speech spectrum (ULTASS), whereas there were small differences from ULTASS noticed for Indian English and Kannada. This difference was especially significant at low frequencies. This difference is reasoned out as the procedural-, speaker- and language-related influence on LTASS.

II. Real ear objective measures

1. Insertion gain measurements

Findings of the current study revealed that gain prescribed by NAL-NL1 is not adequate for the languages i.e., Indian English and Kannada considered in the study, at moderate levels of the signal inputs. The findings also revealed that Indian English requires more gain compared Kannada at low and mid frequencies. The reason for this finding is attributed to the structure and phonemic variations between the two languages considered in the study.

2. Visible speech measures.

a) Aided LTASS

Findings of the present study revealed that there was a no significant difference between Indian English and Kannada, when the hearing aid was programmed to NAL-NL1 setting, for all the three frequencies (low-, mid- and high-) across all the 4 degrees of hearing loss considered in the study. The only exception to this trend is for high frequency in moderately severe group, wherein the SPL of two languages were found to be significantly different from each other.

This can be attributed to the effect HLD factor i.e., the individuals falling in the lower range (56- 60 dB HL) of moderately severe group has less effect of severity of hearing loss on audibility of speech sounds as compared to the higher range (61- 70 dB HL) . Greater the degree of HL, lesser the audibility and lesser the cues (SPL) available in the ear canal, for speech perception.

For hearing aid set to optimized settings, no difference in LTASS existed between the languages. This shows that when hearing aid is fined tuned, optimal benefit can be derived from it, irrespective of the differences in the languages.

b) Aided SII

There was a significant difference between Indian English and Kannada in SII, for the NAL-NL1 setting, especially in the lower degrees of hearing losses (mild and moderate). The significant difference decreased as the degree of hearing loss increasedand the difference was nullified for severe degree of hearing loss. This again can be attributed to the effect of severity of loss on audibility of speech sounds. However, when the hearing aid is set to the optimized settings, such difference between the languages is not seen, indicating the optimal benefit derived due to fine tuning the hearing aid.

3. Speech identification scores.

Speech identification scores for the sentences show that most of the participants of the study performed well for the Kannada language as compared to English. This was true for both hearing set to NAL-NL1 and optimized programsand across all the degrees of hearing loss. This finding reveals the role of proficiency of L1 in supplementing the redundant cues, leading to high scores in Kannada.

Thus, from the above findings of the study, it is evident that gain prescribed by NAL-NL1 is inadequate for the languages considered in the study. The gain prescribed by NAL-NL1 needs to be fined tuned according to the language structure. This is specifically very relevant in Indian context where most individuals speak and listen to a SOV (usually the first language) and SVO (English) language.

Thus from the findings of the present study, the null hypothesis stating that there is no significant difference in the amplification required for conversational level (45 dB HL) of sound inputs for SVO (Indian English) and SOV (Kannada) languages when compared to NAL-NL1 is rejected.Taking this finding of the study in cognizant, in clinical setting when a hearing aid is programmed to NAL-NL1, it is recommended to consider additional gain requirements for the languages considered in the study.

In addition to the above, the findings of the study substantiate the need for the inclusion of IG measurements and visible speech measurements in understanding the benefits derived from the hearing aid. The study also throws light on the importance of correlating all the objective measures along with subjective measuresavailable for hearing aid gain verification, before prescribing a Hearing aid. Thus, the knowledge on impact of language structure on the hearing aid programming can aid the audiologists in maximizing the benefits derived from the hearing aid, which in turn would serve to enhance the satisfaction levels of the hearing aid user.

Future directions for research:

1. This study is one of the preliminary attempts made in the direction of understanding the impact of language differences on hearing aid programming. The study can be performed on a large population to check if the findings can be generalized.

2. Furthermore, the study is done only on the flat hearing loss and gradually sloping SNHL. There is a need to study the same for other configurations and types of hearing loss to check if similar findings can be generalized to such individuals with hearing impairment as well.

3. Additional research is warranted to confirm these findings, by controlling the variables that affect speech perception such as the procedural-, talker-and language - specific aspects.

4. The study has taken Indian English and a Dravidian language i.e., Kannada for understanding the effect of language variations i.e., SOV and SVO on hearing aid gain prescription. But it remains to be confirmed if the same trend is noticed in the other Dravidian languages (such as Tamil, Telugu and Malayalam) and Aryan languages such as Hindi.

5. If the findings of the study are found to be replicated by other, then a need for a new language specific prescriptive formula for SOV languages in Indian context is warranted.

Thus, the current study throws light on the importance of the understanding of the subtle but important integrities like language differences in hearing aid programming for SVO and SOV languages.

To conclude this study, I would like to end quote the words of Byrne (1998), “A challenge for the profession is to device fitting procedures that are scientifically defensible and the challenge for the individual audiologist is to choose the best procedures, from whatever are available, bearing in mind the variables which limit the optimal benefit derived from the device". (NAL-NL2 for ASA 2010 notes.ppt, retrieved from www.nal.gov.au/pdf/, 5/5/2013).

References

Aazh, H., & Moore, B. C. J. (2007).The value of routine Real Ear Measurement of the gain of Digital Hearing Aids.*Journal of the American Academy of Audiology*, *18 (8)*, 653–664.

Ackerman, L., Hesterberg, L., &Bradlow, A.R. (2012).Talker and language variation in the F_0 of English, Mandarin and Mandarin-accented English. Poster Presented at 86th*Annual Meeting of Linguistic Society of America*, Portland.

Achaiah, M. A., & Narne, V. N. (2011). Comparison between outcomes using preferred gain and prescribed gain formulae in experienced adult hearing aid users. Submitted as a part of Dissertation 783.University of Mysore. Mysore.

Abercrombie, D. (1964). Syllable quantity and enclitics in English.In Honour of Daniel Jones. London: Longmans.

American National Standards Institute (1997, R 2012).Standards for calculation of the Speech Intelligibility Index.ANSI S3.5-1997. New York. American National Standards Institute.

Andrews, G., & Ingham, R. (1971).Stuttering: Considerations in the evaluation of treatment.*British Journal of Communication Disorders*, *6,* 129-138.

Boersma, Paul &Weenink, David (2007).Praat: doing phonetics by computer (Version 4.6.09) [Computer program]. Retrieved August 23.2012. fromhttp://www. praat.org/

Bradlow, A. R., Torretta, B. M., &Pisoni, D. B., (1996). Intelligibility of normal speech I: Global and fine-grained acoustic-phonetic talker characteristics. *Speech Communication 20*, 255–272.

Byrne. D., Dillon. H., Tran. K, Cox. R., Hagerman. B., Hetu. R., Kei. J., Lui. C., et al. (1994).An international comparison of Long term average speech spectrum.*Journal of the Acoustic Society of America, 96 (4)*, 2108-2120.

Byrne.D., Dillon, H., Ching, T., Katsch, R., & Keidser, G. (2001). NAL-NL1 procedure for fitting Nonlinear Hearing Aids: Characteristics and comparisons with other procedures. *Journal of the American Academy of Audiology, 12 (1),* 37–51.

Carhart.R., & Jerger, J. (1959).Preferred method for clinical determination of pure tone thresholds.*Journal of Speech and Hearing Disorders, 24 (4)*, 330-345.

Census (2001).Talen per staat. Censusindia.gov.in. Retrieved 04-3-2013.

Chasin, M. (2008). How hearing aids may be set for different languages? *The Hearing Review*, 15(11), 16–20.

Chasin, M. (2011).Setting Hearing Aids differently for different Languages.*Seminars in Hearing 32 (2)*, 182-188.

Chasin, M. (2012 a). How much gain is required for soft-level inputs in some Non-English Languages? *The Hearing Review,19,* International edition.

Chasin, M. (2012 b). Sentence Final Hearing Aid Gain Requirements of Some Non-English Languages.Canadian *Journal of Speech-Language Pathology and Audiology*.36 (3).196-201.

Chen, Y., Robb, M. P., Gilbert, H. R., &Lerman, J. W. (2001).A study of sentence stress production in Mandarin speakers of American English. *The Journal of the American Academy of Audiology, 109,* 1681 – 1690.

Computerized Speech Lab, Model 4500. Kay Elemetrics Corporation, Lincoln Park, NewJersey.

Cornelisse, L. E., Gagne, J. P., &Seewald, R. C. (1991).Ear level recordings of the long-term average spectrum of speech. *Ear and Hearing,12 (1)*, 47-54.

Cornelisse, L. E., Seewald, R. C.,& Jamieson, D.G. (1995). The input/output (i/o) formula: A theoretical approach to the fitting of personal amplification devices. *Journal of the American Academy of Audiology, 97,* 1854-1864.

Cox, R. M, & Moore, J. N. (1988).Composite speech spectrum for hearing aid gain prescriptions.*Journal of Speech and Hearing Research, 31,* 102-107.

Cutler, A. & Ladd, D.R. (1983). Prosody: models and measurements. *Journal of Linguistics, 21*, 226-231.

Dillon, H. (1999). NAL-NL1: A new prescriptive fitting procedure for non-linear hearing aids. *TheHearing Journal*, 52(4):10-16.

Dillon, H., Keidser, G., Ching, T., Flax, M., & Brewer, S. (2010). Development of the NAL-NL2. *XIX Australian Audiological Society National Conference,* Sydney.

Doherty (2013). Excerpted from http://quotationsbook.com/quote/46696/

Emerson (1882). http://en.nordsprog.com/category/Hearing.

Fonix 7000 - Hearing Aid Test System Operator’s ManualVersion 1.70.(2010). Frye Electronics, Inc.

Geetha, C., & Sharath, K. S. (2012).Development of Sentence list in Kannada for Adults.AIISH Research fund (ARF) project, Mysore.

Grabe, E., & Low, E.L. (2002). Durational variability in speech and the rhythm class hypothesis. *Papers Laboratory Phonology, 7*.515–546.

Hazan, V., & Markham, D. (2004). Acoustic-phonetic correlates of talker intelligibility for adults and children. *Journal of the American Academy of Audiology,116 (5),* 3108–3118.

Hodge, M., &Gotzke, C. (2010). Stability of intelligibility measures for children with dysarthria and cerebral palsy. *Journal of Medical Speech Language Pathology, 18(4),* 61-65.

Humes, L. (1996). Evolution of prescriptive fitting approaches. American Journal of Audiology 5.19–23.

Humes, L. E., Dirks, D. D., Bell, T. S., Ahlstrom, C., & Kincaid, G. E., (1986).Application of the Articulation Index and the Speech Transmission Index to the recognition of speech by normal-hearing and hearing impaired listeners.*Journal Speech Hearing Research. 29, 447–462.*

Ingram, J., &Pittam, J. (1987). Auditory and acoustic correlates of perceived accent change: Vietnamese school children acquiring Australian English. *Journal of Phonetics 15*, 127–143.

Institute of Electrical and Electronics Engineers (IEEE) sentences (1969). IEEE Transactions on Audio and Electroacoustics, 17 (3), 225-246.

Kessler, B., &Treiman, R. (1997).Syllable Structure and the Distribution of Phonemes in English Syllables. *Journal of Memory and Language.37 (3),* 295–311.

Kiukaanniemi, H., Soponen, P., & Manila, P. (1982).Individual differences in the long-term speech spectrum.*Folia Phoniatrica. 34*, 21-28.

Killion, M. C., &Fikret-Pasa, S. (1993). The three type of sensorineual hearing loss: Loudness and intelligibility considerations. *The Hearing Journal 4*6 *(11)*.31-36.

Kulshreshtha, M., Singh, C. P., & Sharma, R. (2008). Comparison of accent features embedded in Chattisgarhi and Khariboli Dialect of Hindi for Forensic Speaker Profiling. *Journal of forensic science.3 (1).*1-7.

Kryter, K., (1962). Validation of the articulation index.*Journal of the Acoustic Society of America, 34 (11),* 1698 – 1702.

Lieberman, M. (1967).Intonation, perception and language. MIT Press: Cambridge.

Loizou,&Philipos. (2007). Speech Enhancement: Theory and Practice, retrieved on 7/1/2013 from AIISH digital non - periodicals access. htpp:/ 192.168.102.150/.

Lloyd, L.L., & Kaplan, H. (1978).Audiometric interpretation. Baltimore, MD: University Park press.

Matrix laboratory (MATLAB) Version 7.9.0.529. (R2009b). *Global Optimization Toolbox: User's Guide* Singapore.The MathWorks Inc.

Manjula, R. (1997). Aspects of Kannada Intonation in Discourse/ Interrogatives.Submitted as a part of Ph.D Thesis, University of Mysore.

Mathew, M.M & Butt, J. S (2010).Nature of Sentence Intonation in Kannada, Tulu and Konkani.*Language in India, 10 (4),* 15-25.

Mallikarjun, B. (2010). Patterns of Indian Multilingualism.*Language in India, 10*.1-18.

McCreery, R.W. &Stelmachowicz, P.G. (2011) Audibility-based predictions of speech recognition for children and adults with normal hearing. *The Journal of the American Academy of Audiology*.130(6).

Moore, B. C. J., & Glasberg, B. R. (1997). A model of loudness perception applied to cochlear hearing loss. *Auditory Neuroscience, 3,* 289-311.

Mori, K., Toba, N., Harada, T., Arai, T., Kometsu, M., Aoyagi, M., &Murahara, Y., 1999. Cited in Mary,L. &Yegnanarayana, B. (2008).Extraction and representation of prosodic features for language and speaker recognition.*Journal of Speech Communication, 50 (10),* 782-796.

National Institute on Deafness and Other Communication Disorders (NIDCD) (2012), http://www.nidcd.nih.gov/Pages/default.aspx.Retrived on 04.05.2012.

Nikhil, P. K., & Manjula, P (2009).Verification of Hearing Aid Selection Using Visible Speech and Speech Intelligibility Index.Masters dissertation no: 677.University of Mysore, Mysore.

Nilsson, M., Soili.D., & Sullivan, J. A. (1994).Development of the hearing In Noise Test for the measurement of speech reception thresholds in quiet and in noise.*Journal of the Acoustic Society of America, 95 (2),* 1085-1099.

Noh, H., & Lee, D, H. (2012a). Cross-language identification of Long-Term Average Speech Spectra in Korean and English: Toward a better understanding of the quantitative difference between two languages. *Ear & Hearing*, Vol. 33, No. 3, 441–443.

Pierrehumbert, J. (1979).The perception of fundamental frequency declination.*Journal of the Acoustic Society of America.66 (2).*363-369.

Pittman, A. L., & Stelmachowicz, P. G. (2003). Hearing loss in children and adults: audiometric configuration, asymmetry and progression. *Ear and Hearing, 24(3),* 198-205.

Pradhan, B., &Nikam, S. (1994). *Acoustic Characteristic of Nepali Language (Long Term Average Speech Spectrum).*Unpublished Independent project no: 226,University of Mysore, Mysore.

Rajapurohit, B. B. (1982). Acoustic characteristics of Kannada.Central Institute for Indian Languages (CILL) Monographs series 24. CILL, Mysore

Ranganatha, M. R. (1982). Morphophonemic Analysis of Kannada Language:relative frequency of phonemes and morphemes in kannada. Central Institute for Indian Languages (CILL) occasional monographs series 17. CILL, Mysore.

Rathna, N., &Bhardwaja, A. (1977).Rate of speech in different Indian languages, *TheJournal of All India Institute of Speech and Hearing,8,* 57-60.

Rupela, R., & Manjula, P. (2002).*Long term average speech spectrum in Hindi.* Unpublished Independent project no: 421,University of Mysore, Mysore.

Russel,K. (1997). Cited in Intonation Contours in English.Patil, Shanker, G., Ashritha, K., Radhini, C., Jyothi, N. V. (2010).*Language in India. 10*. 93.

Rao, P., Bharati, A., Sangal, R., &Bendre, S. M. (2003).Recent advances in natural language processing. *Proceedings of the International Conference on Natural Language Processing* (ICON), Mysore.

Samuel, M. C., & Yathiraj, A.(2002). *Long term average speech spectrum in Malayalam.* Unpublished Independent project no: 411,University of Mysore, Mysore.

Sairam V. V. S., & Manjula, P. (2002).*Long term average speech spectrum in Kannada.* Unpublished Independent project no: 422,University of Mysore, Mysore.

Savithri, S., R. (1989).Acoustic and psychological correlates of speech.*Journal Acoustic Society India.17(3&4).*1-8.

Savithri, S.R., Rohini, H., & Sairam, V.V.S. (2005).Duration as a cue for stress perception in Kannada.*Journal of the Indian Speech and Hearing Association,19,* 67-70.

Savithri, S. R., Goswami, S &Kedarnath, D. (2007).Speech rhythm in Indo-Aryan and Dravidian Languages.*Proceedings of the International Symposium on Frontiers of Research on Speech and Music*.170-174.

Scollie, S. D. (2008). Children's Speech Recognition Scores: The Speech Intelligibility Index and Proficiency Factors for Age and Hearing loss. *Ear & Hearing.29(4).*543 - 556.

Shen, X. (1990). Ability of learning the prosody of an intonational language by speakers of a tonal language: Chinese speakers learning French prosody. *Int. Rev. Appl. Ling. Lang. Teach.* 28, 119–134.

Studebaker GA, Sherbecoe RL, McDaniel DM, Gray GA. (1997). Age-related changes in monosyllabic word recognition when audibility is held constant. *Journal of the American Academy of Audiology* 8:150-162.

Summer Institute of Linguistics (SIL) Ethnologue Survey (2009).Summer Institute of Linguistics.

Tarnoczy, von T. (1971).Das durchschnittlicheenergie-spektrum der sprache (fur sechssprachen).*Acustica24,*57-74.

Wong,L. L. N., Ho, A. H.S., & Chua, E. W. W. (2007).Development of the Cantonese speech intelligibility index.*Journal of the Acoustic Society of America.121(4),* 2350–2361.

Wylie, E & Ingram, D. E. (2006).International Second Language Proficiency Ratings (ISLPR), ISLPR language service, Mt Gravatt, Griffith University, Brisbane.

Yathiraj, A. & Vijayalakshmi, C. S. (2005).Phonemically Balanced Word List in Kannada. Developed in Department of audiology, AIISH, Mysore.

Zalewski, J., &Majewski, W. (1971). Polish speech spectrum obtained from superimposed samples and its comparison with spectra of other languages. *Proceedings of the 7th ICA, Budapest*, 249-252.