Comparison of Functional Gain and Insertion Gain in Linear and Non-linear Hearing Aids

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Abstract

Hearing aid selection and fitting is a step-wise procedure involving hearing evaluation, pre-selection of hearing aid, hearing aid fitting, verification of hearing aid, and validation. As verification is one of the important steps, there is a need to evaluate the subjective and objective verification measures for the linear and non-linear hearing aids. This is because these hearing aids differ in terms of the amount of gain they provide at different input levels. To evaluate the effectiveness of the verification measures, 20 children with hearing impairment using hearing aids participated in the study. These children were in two age groups, Group I with 4+ to 5 years, and Group II with 5+ to 6 years. The results indicated no difference for insertion gain measures between the two age groups. The results also revealed that either the IG or FG can be used as verification measures, for linear hearing aids. This is because both of them provide comparable results for linear hearing aids. However, the values of FG and IG were different for non-linear hearing aids. The IG measures carried out at different levels reflected the non-linear functioning of a hearing aid.

Key words: verification measures, intensity levels, pure tone signal, ANSI digi speech signal.

Introduction

Consistent audibility of speech at levels ranging from soft to loud is a pre-requisite for the development of spoken language. This fact is reflected in the Paediatric Amplification Guidelines (2004) by American Academy of Audiology. These guidelines state that the goal of amplification for children with significant hearing impairment is 'to provide a hearing aid that makes low, moderate, and high intensity sounds audible but not uncomfortable and provide excellent sound quality in a variety of listening environments'.

A hearing aid amplifies the weak sounds as well as moderate to loud level of sounds. The linear hearing aids apply the same amount of gain to the incoming sounds regardless of the level of sounds entering the hearing aid (Palmer, Lindley, & Mormer, 2000). Whereas in a non-linear hearing aid, more gain is applied to the soft sounds and lesser gain is applied to louder sounds. Thus, the verification of hearing aid fitting should reflect such a change in the response of the client while using these hearing aids.

Currently available hearing aid verification tools such as functional gain measurement which is a behavioral measure, is the difference in the unaided and aided hearing thresholds in a sound field (Stelmachowitcz, Hoover, Lewis, & Brennan, 2002). The functional gain (FG) is the measurement done only at one level and hence it reflects the hearing aid gain at

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only one input level or at low input levels. Thus, the FG seems to be more appropriate for evaluation of linear hearing aids that give a constant gain irrespective of the level of the input signal (Kuk & Ludvigsen, 2003). Tharpe, Fino-Szumski, and Bess (2001) reported that approximately 60% of the audiologists verify hearing aid gain and frequency response settings for young children using behavioral measures such as sound field thresholds. In the school settings, nearly 80% of audiologists use these measures to adjust and fit the hearing aids. For evaluating the non-linear hearing aids, one of the limitations of FG lies with the fact that the FG represents only the response of the hearing aid for low level of signal (Tecca, Woodford, & Kee, 1987). Thus, FG is not an appropriate measure to evaluate non-linear hearing aids that provide different gain at different levels of input signals.

In recent years, there has been increased interest in the use of articulation index (AI) not only for assessing the audibility of speech but also for measuring the potential effectiveness of the amplification systems. This interest has been reinforced because of the ability of the AI to explain the amount of difficulty the person with hearing impairment will have in understanding speech (Kamm, Dirks, & Bell, 1985). The practical application of AI also has been fueled by the popularity of prescriptive fitting strategies and the development of computerized probe-microphone measures (Mueller & Killion, 1990).

The Real Ear Insertion Gain (REIG) measurements take all these parameters into consideration. The Real Ear Insertion Gain (REIG), an objective equivalent of functional gain measure, is determined by measuring the Sound Pressure Level (SPL) at the ear drum without a hearing aid i.e., the Real Ear Unaided Gain (REUG) and subtracting this from the SPL at the ear drum with the hearing aid in the ear i.e., Real Ear Aided Gain (REAG) (Hawkins, 2004). In order to know how the hearing aid functions at different input levels, insertion gain measurement would be more appropriate. The insertion gain (IG) measurement provides a quick, more reliable and efficient method of quantifying the in-situ performance of hearing instruments than the functional gain method (Stelmachowtcz, Hoover, Lewis, & Brennan, 2002).

Need for the study

To assess the suitability of different signal processing strategies for children who have hearing impairment from early life, it is important to evaluate the strategies using a representative sample of those children, rather than generalizing or extrapolating from results derived from adult subjects with acquired hearing loss. There is relatively little published research on the use of non-linear amplification for young children, although there are a few studies with older children and adolescents (Bamford, McCracken, Peers, & Grayson, 1999). Hence, there is a need to compare the functional gain measurement with insertion gain measurement, as the functional gain is difficult to obtain from paediatric population.

For evaluation of the non-linear hearing aid, it is possible to measure the gain provided by the hearing aid at different levels of the input signal using insertion gain measurement (ASHA, 1997, Paediatric Working Group, 1996). Objective measures such as insertion gain can depict the gain provided by different hearing aids at different levels as it can assess the hearing aid circuitry at different levels which is not possible through the subjective measures such as functional gain for warble tone. The current study attempts to compare the usefulness of insertion gain measurement with that of functional gain measurement for verification of the performance of linear and non-linear hearing aids. The prescriptive procedures for non-linear hearing aids use different target gains for different levels of the input signals and the hearing aid gain is adjusted to match these targets. This provides valuable information like audibility of speech over a range of commonly experienced input levels such as soft, average and loud speech. Hence, it is necessary to compare the FG and IG of hearing aids to see if one can be used instead of the other for hearing aids using different technologies (Hawkins, 2004).

The objectives of the study included comparison the insertion gain (IG) of hearing aid across the age groups in children; comparison of different types of signals used for insertion gain measurement; comparison of linear and non-linear program modes using insertion gain measurement; comparison of insertion gain (IG) and functional gain (FG) for linear and non-linear hearing aids; and finally to investigate the relationship between the speech identification scores and the articulation index derived from the insertion and functional gain measures.

Method

Participants

Twenty children with hearing impairment using hearing aids participated in the study. The children used different models of Behind-The-Ear (BTE) hearing aids, and all of them wore their hearing aids through most of their waking hours, i.e., not less than eight hours per day. The participants had moderately severe to profound degree of sensorineural hearing loss. All the participants were native speakers of Kannada language attending the pre-school and/or individual therapy session at All India Institute of Speech and Hearing, Mysore. All the participants were at or above the stage of closed-set word identification. The participants were divided into two groups. Group I consisted of four male and six female children in the age range from 4+ to 4.11 years (mean = 4.4 & SD = 0.33). Group II consisted of two male and eight female children in the age range from 5+ to 5.11 years (mean = 5.56 & SD = 0.37)

Instruments / Material used

A calibrated sound field audiometer (Madsen OB922, version 2) was used. A calibrated hearing aid analyzer (Fonix 7000 Hearing Aid Test System, version 1.8) also used. Aided Testing was done with a digital BTE hearing aid, coupled with custom ear mold. This hearing aid had six channels with a fitting range from moderate to profound degree of hearing loss. The hearing aid was programmed in two different program modes:

i) Non-linear program mode
ii) Linear program mode

Hardware and software was used to program the hearing aids, i.e., a personal computer connected to HIPRO for programming the hearing aid. The NOAH software (version 3.1.2) and the hearing aid specific software (Aventa, version 2.6) along with WinCHAP (Computerized Hearing Aid Program for Windows, version 2.82) software were installed in this personal computer. Picture identification test material in Kannada was developed by Vandana (1998). This had four lists, each with 25 bi-syllabic PB (phonemically balanced) words.

Procedure

The testing was performed in an air conditioned sound treated double or single room environment.

Stage I: Optimization of Parameters for Non-linear and Linear Program Modes

Initially the hearing aid was programmed in ‘auto-fit’ feature for linear mode in the hearing aid specific software. For optimizing the hearing aid program in linear mode, insertion gain measurement was carried out. The hearing aid gain was matched with that of the NAL-R target gain. This was stored as Program 1 (P1) of the hearing aid.

In a similar way, the gain was also programmed for the non-linear mode and the hearing aid parameters were optimized to match the NAL-NL1 prescription (Dillon, 1999). As the NAL-NL1 formula is for non-linear hearing aids, it provides more gain for the soft level of sounds, and lesser gain for higher level of sounds. As there were two separate programs available in the test hearing aid, the NAL-R setting was stored in Program 1 (P1) and the NAL-NL-1 settings was stored in Program 2 (P2) of the hearing aid.

In each age group and for each participant, the measurement was done only for one ear, equal numbers of right and left ears were considered. Custom made soft ear molds were used to couple the test hearing aid to the ear of the participant during the measurement.

Stage II: Verification of Hearing Aid Fitting Through Insertion Gain Measurement

Verification through insertion gain measurement was done using pressure method of sound field equalization. In this method, the reference microphone was placed as close to the hearing aid microphone as possible during the measurement. The reference microphone monitored the SPL reaching the hearing aid from the loudspeaker of the Fonix 7000 hearing aid analyzer.

After setting up the participant and the instrument for insertion gain measurements, the Win CHAP (windows based Computerized Hearing Aid Program) software enabled for storing the participant’s data and hearing aid data. The IG measurement was carried out for pure tone and ANSI digi speech signals for linear and non-linear program modes for each of the participant.

1. Data tabulated from unaided response for pure tone and ANSI digi speech signal included: Real ear unaided gain (REUG) for three input levels (50 dB SPL, 65 dB SPL and 90 dB SPL) at different frequencies.
2. Data tabulated from aided response for pure tone and ANSI digi speech signal for linear and non-linear program modes of the hearing aid included: Real ear aided gain (REAG) for three input levels signal of (50 dB SPL, 65 dB SPL, and 90 dB SPL) at different frequencies.
3. Insertion gain was obtained by subtracting the unaided gain from the aided gain at different frequencies, separately for all the three different levels, i.e., at 50, 65, and 90 dB SPL for linear program mode. The different frequencies at which the insertion gain were noted were 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz. For each of the participant, a similar procedure was carried out for non-linear program mode of hearing aid also.
4. Articulation Index (AI) calculation from insertion gain method.
5. The count-the-dot method for calculating the AI was utilized to convert the REIR into the AI values, as recommended by Mueller and Killion (1990). The AI was calculated for three different levels 50, 65, and 90 dB SPL for linear as well as non-linear program modes. Thus, for each participant six AI values - three in linear program mode & three in non-linear program mode - were obtained.

Stage III: Functional gain measurement (FG measurement)

The functional gain, using aided thresholds and Speech Identification Scores (SIS), were measured for linear and non-linear program modes of the hearing aid for each participant.

a. The FG measurement was carried out with a calibrated sound field audiometer. The loudspeaker was located at a distance of one meter and 45 ° Azimuth from the test ear of the participant, in the calibrated sound field. For the measurement of FG, the unaided thresholds for warble tone signals were obtained. The aided thresholds, obtained after fitting the hearing aid in linear program mode and later in the non-linear program mode, were measured at octave and mid-octave intervals from 250 to 6000 Hz. The difference between unaided and aided threshold at each of these frequencies were computed to obtain the functional gain at that frequency.

b. The count-the-dot method for calculating the AI was utilized to convert the aided thresholds into the AI values, as recommended by Muller and Killion (1990). For each participant two AI values (one in linear program mode & one in non-linear program mode) were obtained.

c. Further, the unaided and aided SIS were also obtained, using speech identification test in Kannada (Vandana, 1998), at three levels which was equivalent to the presentation levels used during insertion gain measurement. The SIS was measured for linear as well as non-linear program modes at 35 dB HL, 50 dB HL, and 75 dB HL (equivalent to 50, 65, & 90 dB SPL respectively).

For each of the participant, a total of 25 words were presented at each of the above mentioned presentation levels. The closed set response mode was used to elicit the responses at each level. Both the order of the test material and level of presentations were randomized. The scoring was done by noting the number of correct pictures being identified. Each word identified correctly was given a score of one and the incorrect identification was given a score of zero. The maximum score was 25 as there were 25 words in the word list. The same procedure was followed for both linear as well as non-linear program modes of the hearing aid, for each participant.

Results and Discussion

Descriptive statistics and the tests of significant difference were carried out on the data using Statistical Package for the Social Sciences (SPSS) software. Results revealed that the insertion gain measure was not significantly different for both the age groups. But the functional gain and insertion gain measures differed with respect to the level of the signal and the program mode used.

1. Insertion gain for pure tone and ANSI digi speech signals in linear and non-linear program modes for Group I and Group II.

In order to know if the difference between pure tone and ANSI digi speech was significant, mixed ANOVA was done. The frequencies were grouped into low (200 and 500 Hz) , mid (1000 and 2000 Hz) and high (4000 and 6000 Hz) frequencies. The average IG at the low-, mid- and high- frequency regions in linear and non-linear program modes for pure tone signal along with the significance of difference is given in Table 1.

Table 1. IG difference between Group I and Group II across frequencies at 50 dB SPL, 65 dB SPL, and 90 dB SPL for pure tone signals, in linear and non-linear program modes.

Frequencies	*Intensity level (in dB SPL)*	*Significant difference between Group I and Group II*	
		IG for linear	*IG for non-linear*
Low frequencies	50	$F(1,18) = 0.42$	$F(1,18) = 0.69$
	65	$F(1,18) = 0.00$	$F(1,18) = 0.34$
	90	$F(1,18) = 0.63$	$F(1,18) = 0 .52$
Mid frequencies	50	$F(1,18) = 0.65$	$F(1,18) =0.60$
	65	$F(1,18) = 0.04$	$F(1,18) = 0.94$
	90	$F(1,18) = 0.09$	$F(1,18) =0 .61$
High frequencies	50	$F(1,18) = 5.18$*	$F(1,18) = 1.15$
	65	$F(1,18) = 0.60$	$F(1,18) = 1.42$
	90	$F(1,18) = 0.17$	$F(1,18) = 1.27$

Note: ***** **=** significant difference at $p < 0.05$ level

For pure tone signals, in linear as well as for non-linear program modes, the mixed ANOVA revealed that there was no significant difference in the mean IG between the two age groups for pure tone signals at all frequencies, with an exception at 50 dB SPL for high frequencies ($p<0.05$) in linear program mode.

Similarly, for mean ANSI digi speech signal also, mixed ANOVA revealed no significant difference in the mean IG between the two age groups. This was true for the low-, mid- and high- frequency regions at different intensities in linear and non-linear program modes (Table 2).

Table 2: IG difference between Group I and Group II across frequencies at 50 dB SPL, 65 dB SPL, and 90 dB SPL for ANSI digi speech signal, in linear and non-linear program modes.

Frequency	*Intensity level (in dB SPL)*	*Significant difference between Group I and Group II*	
		IG for linear	*IG for non-linear*
Low frequencies	50	$F(1,18) = 0.06$	$F(1,18) = 0.69$
	65	$F(1,18) = 0.34$	$F(1,18) = 3.78$
	90	$F(1,18) = 0.13$	$F(1,18) = 0.08$
Mid frequencies	50	$F(1,18) = 0.86$	$F(1,18) = 0.98$
	65	$F(1,18) = 3.58$	$F(1,18) = 1.76$
	90	$F(1,18) = 1.15$	$F(1,18) = 1.63$
High frequencies	50	$F(1,18) = 2.13$	$F(1,18) = 3.78$
	65	$F(1,18) = 4.76$	$F(1,18) = 4.33$
	90	$F(1,18) = 1.49$	$F(1,18) = 0.53$

Bentler (1989) reported that the average external ear resonance characteristics for children (three to thirteen years of age) appeared to be similar as adults, but some small differences were noted above 3000 Hz. The difference in measured SPL between adults and children were 3-5 dB. Whereas Seewald, Cornelisse, and Ramiji (1997) have reported the age related differences in the SPL in the ear canal for children from the birth to seven years of age. The current study findings suggested no significant difference in SPL in the ear canal for 4 + to 4.11 years and 5+ to 5.11 years. This might be attributed to the maturational changes in the resonance properties of the external ear not being significant during the four to six years of age.

As, there was no significant difference obtained between the two age groups for insertion gain measures (for both pure tone and ANSI digi speech signals), the data from the two groups were combined for further statistical analyses.

2. Mean and significant difference between the IG for pure tones and ANSI digi speech signals in linear and non-linear program modes:

Figure 1 depicts the mean insertion gain for pure tone signals in linear and non-linear program modes. The mean was computed at three different levels in order to know whether there was a different trend observed for linear and non-linear program modes for pure tone signal. The mean of IG in linear program mode was obtained and paired t-test was administered in order to know whether there was any significant difference between the mean insertion gain at three different levels for pure tone and ANSI digi speech signals, in linear and non-linear program modes, as depicted in Figures 1 and 2.

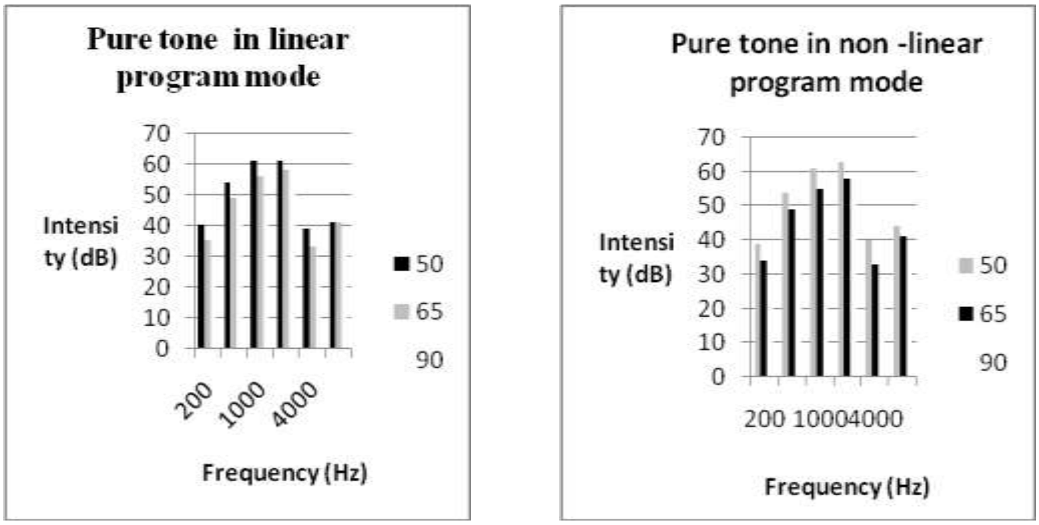


Figure 1: Comparison of mean insertion gain (IG) mean at different frequencies for pure tone signals, in linear and non-linear program modes, at different intensity levels.

For pure tone signals, the mean values for IG at lower levels showed a similar trend for non-linear and linear program modes. This trend was observed for moderate and higher signal levels also. Figure 2 depicts the mean insertion gain for ANSI digi speech signals in linear and non-linear program modes. The mean IG was computed at three different levels in order to know whether there was a different trend observed for linear and non-linear program modes for ANSI digi speech sign

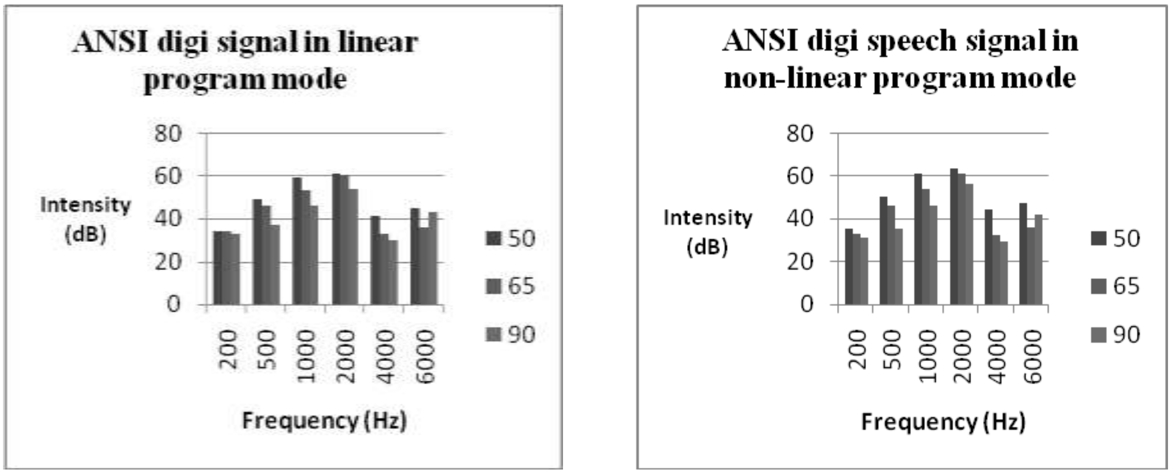


Figure 2: Comparison of mean insertion gain (IG) at different frequencies for ANSI digi speech signals, in linear and non-linear program modes.

From Figure 2, it can be inferred that the mean IG for non-linear program mode is higher than the linear program mode at lower levels of signals across the frequencies. The IG reflected the functioning of the non-linear hearing aid by recording more gain at low input signal levels which was not observed for linear hearing aid. Whereas, the mean IG values were similar for mid and higher levels of ANSI digi speech signals, which indicated both linear and non-linear program modes provided similar amount of gain at moderate and higher signal levels.

These results suggested that the gain varies for the linear and non-linear program modes with respect to the type of input signal used for the measurement. For ANSI digi speech signal and pure tone signal in linear program mode there was a significant difference obtained which suggested that pure tone and ANSI digi speech cannot be substituted for one another. It can be attributed to the amount of gain provided by the hearing aid which varies if the signal spectral and temporal characteristics of the signal are different.

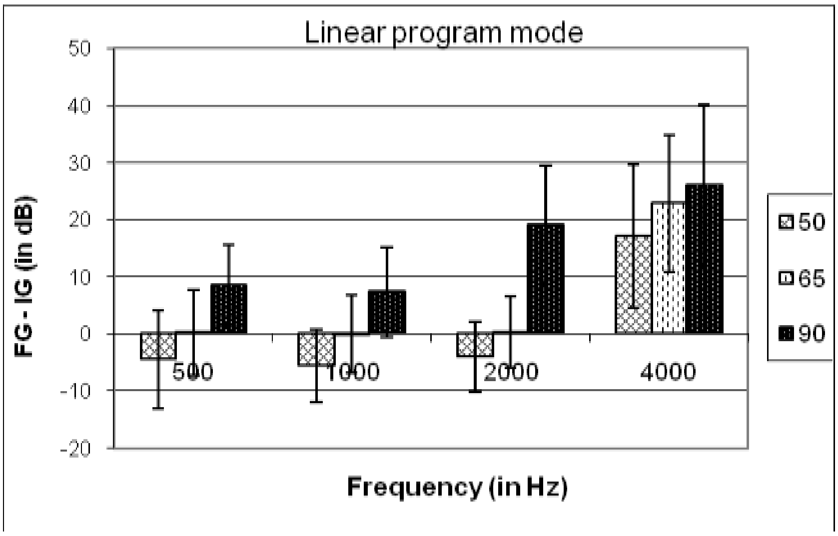
In general, the speech-weighted signals provide a closer match to aided speech levels, than constant-level pure tone sweeps, which tend to overestimate aided output. The findings also suggested that aided levels of pure tone signals should not be used to estimate the aided levels of real speech in sound pressure level. The mismatch between the two types of signals was primarily due to the large difference in input levels between the conventional pure tone sweep and real speech across frequencies. Thus, ANSI digi speech signals are to be used for measurement of insertion gain of hearing aids. Hence, for further analyses only ANSI digi speech signal was considered.

The current study also supported the view that the insertion gain for pure tone and ANSI digi speech signals are significantly different because of their different temporal and spectral characteristics.

3. Difference between FG and IG

The difference between the mean FG and IG was analyzed using descriptive statistics and test for significant difference. The difference between the FG and IG at three intensity levels were computed across the frequencies to find out the mean and SD for linear as well as non-linear program modes. The comparison of mean and SD values for the difference in FG and IG, in linear and non-linear modes, across frequencies are depicted in Figure 3.

The difference between FG and IG were analyzed. The mean and standard deviation (SD) of this difference were obtained at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz at one level of functional gain and all three levels of signal for insertion gain including 50 dB SPL, 65 dB SPL, and 90 dB SPL for pure tone signals in linear program mode. At each of the three input levels for IG, the difference of FG and IG was obtained and the mean and SD were calculated.



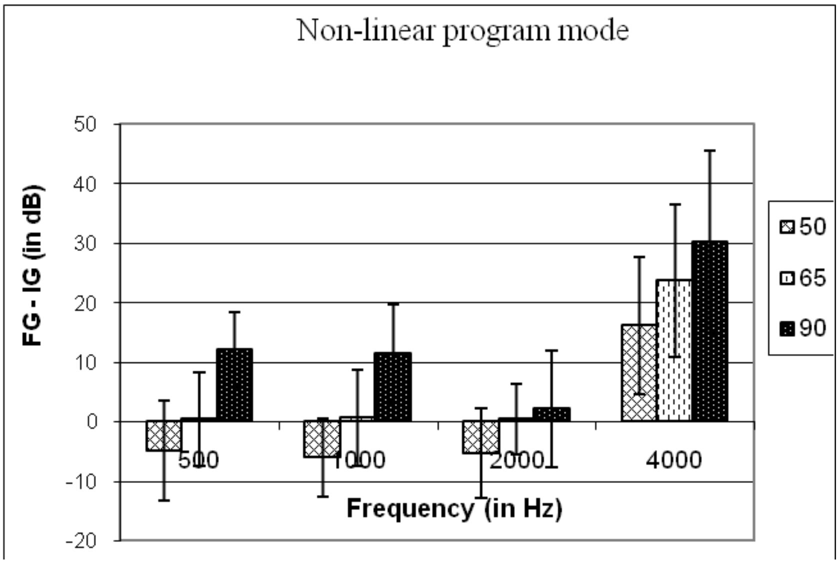


Figure 3: Mean and standard deviation of the difference between FG and IG for pure tone signals at 50 dB SPL, 65 dB SPL, and 90 dB SPL across frequencies for linear and non-linear program modes.

The negative value for non-linear program mode at 50 dB SPL suggests that insertion gain exceeded the functional gain at three frequencies (500 Hz, 1000 Hz, and 2000 Hz). Whereas, at 4000 Hz the mean functional gain value exceeded the mean insertion gain value. The difference between the functional gain and insertion gain at 65 dB SPL for 500 Hz, 1000 Hz, and 2000 Hz was very minimal for linear program mode. The difference between the FG and IG at 90 dB SPL was a positive value, depicting that the FG values exceeded the IG at all the four frequencies (500 Hz, 1000 Hz, 2000 Hz, & 4000 Hz) for linear program mode. In addition, Figure 3 also depicts the difference between mean functional gain and mean insertion gain at for non-linear program mode. The results showed a similar trend as in linear program mode.

The difference between FG and IG is lesser in linear program mode compared to non-linear program mode. This indicates that FG and IG are parallel measures for the linear hearing aids, especially at moderate level of signal. The difference being more for non-linear program mode indicates that the FG and IG are not similar measures. Further, for non-linear program mode, the IG is a more realistic measure as the IG decreased with increase in input intensity.

The IG measure reflected more gain for soft level of signal and moderate gain for moderate level of signal and lesser gain for higher level of signal. Further, IG is a more realistic measure as IG decreases with increase in input intensity. This is because, in the non-linear hearing aids, there in decrease in gain with increase in input level. This cannot be measured or reflected through the FG. FG is mainly a measure which predicts the gain at low levels (at threshold) or moderate levels of signal. Thus, the amount of gain provided at high level of signals cannot be measured through FG, as the FG measured differed from IG at higher levels.

FG and IG difference at 65 dBSPL in the current study were within 8 dB which was close to 5 dB as reported by Mason and Popelka, (1986). This was observed for three frequencies, i.e., 500 Hz, 1000 Hz and 2000 Hz in linear program mode. The FG can be predicted or substituted by IG if the IG measurement is carried out at moderate level of signals. In other words IG and FG provide similar measurements at moderate levels of signals. As the results depicted that the difference between the FG and IG is more at higher signal levels across the frequencies, it is suggested that, FG and IG measures cannot be substituted for each other at low and high signal levels. It provides insight to the fact that for evaluation of the hearing aid performance at higher signal levels, insertion gain is a more realistic measure, which can reflect the non-linear gain.

To find out if FG and IG difference was significant, paired t-test was administered. In the present study for linear hearing aids, it was noted that there was a significant difference between the FG and the IG at low and high levels for pure tones. At moderate levels, there was no significant difference between the FG and the IG at 500, 1000 and 2000 Hz. For non-linear hearing aids, it was noted that the FG and the IG differed significantly at low and high levels of pure tones. But, FG correlated well with the IG at average conversational level. Thus, it is suggested that insertion gain measurement done at moderate level is a better predictor of functional gain measurement. Jenstad, Seewald, Cornelisse, and Shantz (1999) reported that speech intelligibility testing and loudness rating carried out for linear as well as WDRC resulted in equivalent comfort and intelligibility for average input levels. But FG was considerably different from IG at three input levels for linear as well as for non-linear program modes especially for higher frequencies. This suggested that IG at any level (50 dB SPL 65dB SPL, and 90 dB SPL) cannot be used as a substitute for functional gain. Both the measures need to be evaluated independently for high frequency FG or IG measurements.
In the present study, the insertion gain at moderate intensity and the functional gain are the best predictors of the performance of the hearing aids in linear and non-linear program modes, as the correlation of FG and IG was best at conversational level. But, it’s not always

true with non-linear hearing aids. Because the gain provided by the non-linear hearing aid is considerably high at soft signal a level.

4. Relationship between SIS and AI

For linear mode, the relationship between Speech Identification Scores (SIS) at three levels (SIS_{35}, SIS_{50} dB, & SIS_{75} dB) with that of articulation index computed from FG measure (AI_{FG}) and articulation index computed from IG measure (AI_{IG}) was investigated. This was done only for ANSI digi speech signals as its relationship with SIS was being analyzed. This was also done for non-linear program mode, as shown in Table 3. On Pearson's correlation analysis, the correlation was higher with AI_{FG} than with AI_{IG}. in both the program modes.

Table 3: Correlation of Articulation index from the FG (AI_{FG}) and IG (AI_{IG}), in linear and non-linear program modes, with Speech Identification Scores (SIS) at different levels.

Pearson Correlation between		*Linear*	*Non-linear*
SIS $_{35}$	AI_{FG}	r = 0.59*	r= 0.58*
	$AI_{IG,50}$	r = 0.40	r = 0.53*
SIS $_{50}$	AI_{FG}	r = 0.39	r = 0.42
	$AI_{IG,65}$	r = 0.16	r = 0.26
SIS $_{75}$	AI_{FG}	r =0.36	r = 0.10
	$AI_{IG,90}$	r = 0.08	r = 0.04

Note: * = Significant correlation at $p < 0.05$ level

The Pearson's correlation indicated a significant correlation between SIS_{35} and AI_{FG} in linear program mode. Whereas, there was no significant correlation obtained for SIS_{50} with AI_{FG} and SIS $_{75}$ with AI_{FG} in linear program mode. A significant correlation was obtained between SIS_{35} and AI_{FG} in non-linear program mode. Whereas, there was no significant correlation obtained for SIS at other levels and $AI_{FG.}$ The overall trend was similar in both the program modes. Jenstad, Seewald, Cornelisse, and Shantz (1999); Marriage and Moore (2003) reported that the linear hearing aid as well as WDRC (non-linear) hearing aids provided more gain at low input levels (soft speech) than for speech at moderate level. But the processing type and presentation level were not statistically significant in most of the participants. The reason for this might be that WDRC used in their study was a hearing aid with single channel and children with profound hearing loss were using hearing aid with linear amplification strategy. They were not given time for acclimatization with the non-linear hearing amplification strategy.

The present study indicated that AI from functional gain correlated better with the lower level of SIS in non-linear as well as in linear program modes, indicating that AI at soft levels can be a predictor for SIS at soft levels.

On Pearson's correlation analysis, in linear program mode, though there was a positive correlation, it was not significant ($p>0.05$). For non-linear mode, a significant

correlation between SIS_{35} and $AI_{IG,50}$ was noted. Whereas, there was no significant correlation obtained for SIS with AI_{IG} at other levels. In the present study, AI from IG at low levels (50 dB SPL) correlated well with the SIS at 35 dB HL in non-linear program mode. Whereas, there was no significant correlation found for linear program mode between AI_{IG} and SIS at any of the levels. Scollie and Seewald (2002) suggested that the match between the aided test signal and aided speech was different for high level of signals. For the composite signal, the tests at high intensities tended to underestimate the aided speech levels, primarily in the mid- to high-frequency region for linear as well non-linear hearing aids.
Dillon (1993) reported that speech gain in quiet provided by a hearing aid can be accurately predicted from electro-acoustic information comprising of the participant's thresholds, internal hearing aid noise and, and the hearing aid's insertion gain for mild to moderate degree of hearing loss. But, as the hearing loss increases, the distortions such as reduced frequency and temporal resolution makes it less likely that audible energy will continue to be equally useful. This might be the reason in the current study that the IG did not correlate well with the SIS because as the degree of hearing loss increases, the frequency and the temporal resolution become poorer. And also with increase in the degree of hearing loss, more amount of gain is required which in turn induces distortion. Results indicated that in children with moderate to profound degree of hearing loss, the IG measures are not good predictor of the speech measures.

From the study it can be inferred that the IG and FG can be used as verification measures, for linear hearing aids. This is because both of them provide comparative results for linear hearing aids. However, the values of FG and IG were different for non-linear hearing aids. Moreover, the IG measures can be carried out at different levels which provide a better estimation of gain across the frequencies. This is important for evaluating the performance of non-linear hearing aids as it functions differently at different input levels.

For ANSI digi speech signal, the IG were significantly different for linear and non-linear hearing aid indicating that the insertion gain provided by ANSI digi speech differed significantly across the program modes. It revealed functioning of the hearing aid which was different for linear and non-linear program mode though the input level was the same. However, for pure tone signal the insertion gain was similar for linear and non-linear program modes. So, ANSI digi speech signal is a better measure to predict the performance for linear as well as non-linear hearing aid.

For verification of linear and non-linear fitting, the difference between FG and IG was least for moderate level of signals. This suggested that both the measures can be used for verification, if performance of the hearing aid needs to be verified for moderate signal levels. At low and high levels, the difference between FG and IG was more for non-linear program mode compared to linear program mode indicating that the FG and IG should be used as two separate measures. The IG being a better reflector of the hearing aid performance at low and high levels, verification would be effective if performed with IG measure.

The AI from functional gain can be used to predict the SIS for soft signal levels (at 35 dB HL), for linear as well as non-linear program modes. Whereas, AI from functional gain is not a good predictor of SIS at moderate and higher levels (50 dB HL & 75 dB HL).

Clinical Implications

From the results of the present study the following implications can be inferred that:

1) The insertion gain measure can be used as an important tool in order to verify the hearing aid fittings, especially for non-linear hearing aids.
2) Insertion gain can be used as a realistic tool for predicting the hearing aid gain at different signal levels (soft, moderate & loud).
3) As the IG for ANSI digi speech provides more realistic information about real speech, this type of signal should be preferred compared to pure tone signals for verification.
4) Functional gain and insertion both can be used to evaluate the children's performance with the hearing aid at moderate signal levels as they are comparable at moderate levels.
5) The AI from FG measure can be used to predict the SIS, if the SIS is done at low intensity level.

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