Verification of Hearing Aid Selection Using Visible Speech and Speech Intelligibility Index

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Abstract

Verification of hearing aid selection is a major step in the hearing aid fitting process. For verification of hearing aid performance, functional gain measurement for warble tone or speech material and real ear measurements (REM) using tones, composite signals and speech like stimuli are used. The traditional REM utilizes composite noise signals which are not encountered routinely in real life situations and hence inappropriate for testing high end digital hearing aids. The present study was taken up to verify the selection of hearing aids using actual speech. Visible speech measure along with speech intelligibility index was utilized for verification of hearing aid selection. The participant group comprised of 30 naïve hearing aid users, with post-lingual onset of hearing loss. Individuals with hearing impairment were divided into three groups based on degree of hearing loss. Fonix 7000 hearing aid analyzer was used for the traditional real ear measurement protocol which utilizes ANSI-digi speech as stimulus while the visible speech protocol used actual recorded speech. Speech intelligibility index was also tabulated from the visible speech display screen. Speech identification scores were obtained in two different conditions, i.e., when the hearing aid was optimized using traditional real ear aided gain using ANSI-digi speech signal, and other condition was when the hearing aid was optimized using visible speech measure. Findings of the present study reveal that verification of hearing aid using visible speech protocol led to higher speech identification scores. Also, there was a positive correlation between speech identification scores and speech intelligibility index. Hence, verification of hearing aid selection using visible speech protocol and speech intelligibility index yield better performance in individuals with varying degree of hearing loss.

Key Words: Traditional REM, ANSI-digi speech signal, Speech identification scores.

Introduction

The major components in selection and fitting of hearing aid include hearing assessment, pre-selection of hearing aid, fitting, verification, orientation or counselling, and real-world validation (Mueller, 2005). The verification forms one of the major components of this comprehensive protocol. For verification of hearing aid performance, (i) predetermined set of data or fitting target, (ii) functional gain measurement for warble tone and speech material (Burney, 1972), (iii) Real ear measurements (REM) using tones, composite signals and speech like stimuli (Dillon & Keidser, 2003). Of late, real speech or visible speech is being used as a stimulus in REM for the verification of the hearing aid. In addition, Speech intelligibility index (SII) is also being used as one of the reliable verification methods for the selection of hearing aid selection (Cox, Alexander & Revera, 1991).

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The visible speech measure can be used to accomplish verification of hearing aid selection during real ear measurements (Ross & Smith, 2005). 'Visible Speech' also known as 'Live Speech Mapping' (LSM) is the fitting processes that uses probe microphones and live / recorded real-time speech to allow the client and their family members to immediately see and understand the benefits of hearing aids and fitting adjustments**.** The visible speech utilises "real-time speech", that of a family member, friend, or familiar third party, for real-ear measurements. One key difference between this technology and other verification tools is that it allows the client and family to clearly understand the results and realize an immediate and positive impact on their hearing as the programming of their hearing aid is changed.

The SII is calculated from the speech spectrum, the noise spectrum, and the listener's hearing threshold. The SII is determined by accumulation of the audibility across the different frequency bands, weighted by the band importance function. The resulting SII is a number between zero and unity. The SII can be seen as the proportion of the total speech information available to the listener. An SII of zero indicates that no speech information is available to the listener; an SII of unity indicates that all speech information is available.

Need for the study

They are many shortcomings of functional gain measurement in the fitting of the hearing aids. The FG is a subjective test. When speech is used for the measurement of functional gain, it does not assist in making frequency-gain adjustments and also does not reflect which electro-acoustic characteristics that would contribute to better or poorer aided performance. On the other hand, there are various limitations of REM such as they are often made with either tonal or noise stimuli rather than the actual speech. The non-linear digital hearing aids do not faithfully produce the actual gain or output when such test signals are being used. Also, clients find it difficult to relate the data shown on insertion gain and the audibility of actual speech (Poe & Ross, 2005).

To overcome this disadvantage of REM, the REM is carried out using the actual speech that may aid in hearing aid selection. Visible Speech allows the professional to record and demonstrate the appropriateness of the hearing aid fitting while reviewing, demonstrating, and explaining the process in terms the patient understands - based on human speech and the Speech Intelligibility Index (SII). Hence, visible speech along with SII would be of great value to audiologists in determining the performance of a client in real-life situations. It would add to the objectivity and better understanding of the hearing aid benefit by the client.

Aims

The aim of the present study was to investigate the usefulness of visible speech during real ear measurements for selection of hearing aid by

1. Comparing the verification of hearing aid selection done by visible speech with that of real ear aided gain measurements.

2. Comparing the verification of hearing aid selection done by visible speech with that of speech identification scores.

3. Comparing the verification of hearing aid selection done by visible speech with that of speech intelligibility index.

Method

Participants

30 individuals with hearing loss in the age range from 18 years to 75 years (mean age of 52.6 years) participated in the study. They had hearing loss of post-lingual onset and native speakers of Kannada with had adequate speech-language skills. They had flat configuration and sensori-neural type of hearing loss with pure-tone average (PTA) ranging from 41 to 90 dB HL. Their speech identification scores were ≥70%. In the present study, flat type of configuration was operationally defined as the configuration in which the maximum threshold difference between any of the frequencies on the audiogram being not more than 20 dB HL (Pittman & Stelmachowicz, 2003). Individuals with indication of retro-cochlear involvement or central auditory processing disorder or cognitive deficits were excluded from the study. The participants were divided into three groups - moderate, moderately-severe and severe hearing loss group - based on the degree of hearing loss.

Instrumentation

A calibrated sound field audiometer, two commercially available digital BTE hearing aids, two personal computers, one connected to the auxiliary input of the audiometer for presentation of speech material which was recorded on a CD. The other personal computer, with NOAH (version 3.1.2) and hearing aid specific software connected to the HI-PRO, was used to programme the digital hearing aids. In addition, this latter personal computer with WinCHAP software was used to perform the real ear measurements in all the participants. A calibrated Fonix 7000 hearing aid testing system was used for performing the real ear measurements through WinCHAP.

Test material

The phonemically balanced (PB) word lists in Kannada developed by Yathiraj and Vijayalakshmi (2005) was used in the study. The speech material consisted of four phonemically balanced word lists and each list had 25 words. The speech material was digitally recorded using Adobe Audition - 2 software in an acoustically treated room, on a data acquisition system using 44.1 kHz sampling frequency and 16 bit analog to digital converter. A standardized recorded Kannada story (Sairam, 2002) with all the speech sounds of the language was used as the stimulus for the measurement of visible speech and speech intelligibility index.

Procedure

The testing was carried out in an air-conditioned single or double room sound treated environment. The experiment was carried out in the three stages for each of the two hearing aids, for each participant.

Stage 1. Hearing aid programming to for NAL-NL1 prescription
Stage 2. Optimization of hearing aid using
- 2.1. Traditional real ear measurement protocol
- 2.2. Visible speech protocol

Stage 3. Verification using speech identification scores
- 3.1. Speech identification scores: Hearing aid optimized for traditional real ear measurement protocol
- 3.2. Speech identification scores: Hearing aid optimized for visible speech protocol

Stage 1: Hearing Aid Programming for NAL-NL1 prescription

The participant was fitted with programmable digital behind-the-ear (BTE) hearing aid. The hearing aid was connected to a personal computer through a HI-PRO interface unit. The NOAH software (version 3.1.2) along with hearing aid specific software (Electone Connexx V6.1 & Aventa 2.6) was used to programme the hearing aid for the participant. Initially, the hearing aid was programmed with NAL-NL1 using the first fit feature in the software. It should be noted that the fine-tuning of the hearing aid was not attempted at this stage.

Stage 2: Optimization of hearing aid

Hearing aid was optimized using the traditional real ear measurement protocol and the visible speech protocol.

2.1 Optimization of hearing aid using traditional real ear measurement protocol

In this stage, the hearing aid was optimized for NAL-NL1 targets using traditional real ear measurement protocol which utilizes ANSI-digi speech like stimulus as the input signal.

Once the equipment was set-up, the traditional real ear measurement was carried out using Fonix 7000 and WinChap. That is, the real ear unaided measurement for ANSI digi speech signal at 65 dB SPL was carried out. The 65 dB SPL ANSI-digi speech signal that was presented through the loudspeaker of Fonix 7000 was picked up by the probe tube mic in the unaided ear canal. The Fonix 7000 measured this signal in the unoccluded ear canal.

For real ear aided gain (REAG), the hearing aid was fitted on the participant without disturbing the length of probe tube in the ear canal. The hearing aid was switched on. The test protocol as shown in Table 1 was followed for REAG measurement. 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 parameters to meet NAL-NL1 the target at moderate level input.

Table 1: Protocol for REUG / REAG and Visible Speech.

Parameter	REUG / REAG Protocol	Visible Speech & SII protocol
Type of the Stimulus	Digi-Speech, ANSI	Recorded paragraph in Kannada
Level of stimulus :	65 dB SPL	65 dB SPL
Location of integrated probe microphone set :	Participant's pinna	Participant's pinna
Reference microphone :	Enabled, located over pinna	Enabled, located over pinna
Prescriptive formula:	NAL-NL1	NAL-NL1
Output limiting:	125 dB SPL	125 dB SPL

2.2 Optimization of Hearing Aid using Visible Speech Protocol

In this particular stage, the hearing aid was optimized for NAL-NL1 targets using visible speech protocol which utilizes actual speech as the input signal. The participants was seated in the calibrated position in the sound field with speech material (Standardized Kannada passage) being presented through the loud speaker of the audiometer positioned at 45^0 Azimuth and at a distance of 1 meter. The hearing aid was fitted on the participant without disturbing the location of probe tube in the ear canal. The hearing aid was switched 'on'.

The participant's audiogram was entered in the Fonix 7000 to generate mid-level target (65 dB SPL). The external signal, a Kannada story passage was played through windows media player in the computer. This was routed through an audiometer. The output from audiometer was given to the loudspeaker. This signal was picked up by the hearing aid worn by the participant. The Visible Speech measurement on the Fonix 7000 analyzer was initiated.

If the output of the hearing aid did not match the desired target level, then the hearing aid was further optimized. The hearing aid was optimized to match the visible speech targets based on the visible speech procedure. Once the hearing aid output matched the real ear NAL-NL1 targets at most of the frequencies then the following data that was displayed on the monitor of PC were tabulated for each participant for the purpose of analysis.

1. RMS amplitude in dB SPL, of the response of visible speech spectrum.
2. Response amplitude in dB SPL, of visible speech spectrum at 250 Hz, 500 Hz, 750 Hz, 1 kHz, 1.5 kHz, 2 kHz, 3 kHz and 4 kHz.
3. Speech Intelligibility Index, SII (re: ANSI S3.5 - 1997). The SII ranged from 0 to 100, 0 indicating that no audibility of speech signal and 100 indicating the complete audibility of speech signal.

Stage 3: Verification of Hearing Aid using Speech Identification Scores

Speech identification scores were obtained with the hearing aid being optimized with traditional REAG with ANSI-digi speech as well as with visible speech measure.

3.1 Speech identification scores with hearing aid optimized using traditional real ear measurement protocol

Speech identification scores (SIS) were obtained in aided conditions when hearing aid was optimized using traditional real ear measurement protocol, i.e., ANSI-digi speech. The aided speech identification scores were obtained once the hearing aid real ear aided gain matched the NAL-NL1 targets, using traditional real ear measurement protocol. The participant was comfortably seated in the test room at a distance of 1 meter and 45^0 Azimuth from the loudspeaker of the audiometer on the side of the aided ear. The presentation level was kept constant at 45 dB HL.

The participant was instructed to repeat the recorded words being presented through the loudspeaker of the audiometer. The responses were scored on a response sheet as the number of words correctly identified. The maximum score was 25 as each list consisted of 25 words. Each correct response was given a score of 1 and each incorrect response was given a score of 0.

3.2 Speech identification scores with hearing aid optimized using visible speech protocol

Speech identification scores were obtained in aided condition when hearing aid was optimized using visible speech protocol. The aided speech identification scores were obtained once the hearing aid output matched NAL-NL1 targets using recorded speech as the input signal. The same procedure as described above was followed to obtain SIS in this stage.

Results and Discussion

Statistical Package for Social Sciences, SPSS (version 16 for windows) was used for analyses of the data. To compare the REAG for ANSI-digi speech signal, visible speech measure, speech intelligibility index and speech identification scores, the correlation analysis was done both collectively on all the participants and independently on each group.

Real Ear Aided Gain using ANSI-Digi Speech Signal

Table 2: Mean and Standard Deviation (SD) of target gain and REAG with two hearing aids, HA 1 & HA 2, for the three groups of participants.

Freq. (Hz)	*HA*	*Groups based on severity of hearing loss*								
		Group I (N= 10)			*Group II (N= 10)*			*Group III (N= 10)*		
		Target Gain (dB)	*REAG (dB)*		*Target Gain (dB)*	*REAG (dB)*		*Target Gain (dB)*	*REAG (dB)*	
			Mean	*S.D.*		*Mean*	*S.D.*		*Mean*	*S.D.*
250	HA1	7.52	7.01	2.87	17.53	14.26	7.04	22.23	22.29	6.12
	HA2		6.85	3.51		12.72	3.99		17.63	3.67
500	HA1	15.06	17.34	3.09	23.54	23.55	5.31	32.71	34.64	3.18
	HA2		15.48	5.56	23.54	22.99	3.92		30.59	3.60
1000	HA1	27.97	31.24	3.05	37.30	37.47	4.25	45.31	47.71	3.39
	HA2		30.86	2.52	37.30	36.56	2.38		44.28	3.61
1500	HA1	33.27	36.26	2.70	44.07	44.49	3.45	51.13	53.42	3.01
	HA2		37.15	2.67	44.07	44.22	2.96		50.07	3.80
2000	HA1	38.5	39.65	3.01	50.25	48.76	4.10	56.36	57.49	3.45
	HA2		40.85	3.22	50.25	48.44	3.16		54.82	3.25
3000	HA1	37.56	36.89	2.40	45.11	44.24	3.92	52.50	52.42	2.80
	HA2		36.20	2.72	45.11	44.67	3.89		50.26	2.88
4000	HA1	36.04	35.62	3.19	41.21	39.48	5.42	48.39	46.47	4.77
	HA2		32.96	3.62	41.21	40.17	2.56		46.80	3.12

The mean and standard deviation (SD) of the REAG for ANSI-digi speech signal for the three groups of participants with two hearing aids (HA1 & HA2) is given in Table 2. It can be observed from the Table 2 that the target gain as per NAL-NL1 is least in the group with moderate hearing loss (HL). As the hearing loss increased, target gain was increased and the group with severe HL showed highest target gain values. The measured real ear aided gain showed the similar trend as that of the target gain. The real ear aided gain was least in group with moderate HL and highest in the group with severe HL.

Bryne and Dillon (1986) performed real ear measurements recommended by NAL fitting method. In their opinion, the fitting was considered acceptable if the difference between the target and the measured values is within ±10 dB. In another study by Aahz and Moore (2007), the frequency-gain response of the hearing aid was modified to better match the NAL-NL1 target better. The investigators had used ±10 dB criteria to consider that the target gain and measured REAG were matched. In the present study too, the difference between the mean target gain and mean measured REAG values for the two hearing aids was within ±10 dB at all the frequencies. Hence, it can be inferred that the REAG matched the NAL-NL1 target at all the frequencies in Group I. Similar results were obtained in the other two groups of participants (Groups II & III).

Visible Speech

The mean and standard deviation (SD) of the Visible Speech amplitude is shown in Table 3. It can be observed from the Table 4.2 that the target values as per NAL-NL1 were least in group with moderate HL.

Table 3: Mean and Standard Deviation (SD) of target and aided VS response with two hearing aids, HA1 & HA2, for three groups of participants.

Freq. (Hz)	*HAs*	*Groups based on severity of hearing loss*								
		Group I (N= 10)			*Group II (N= 10)*			*Group III (N= 10)*		
		Target Response	*Mean*	*S.D.*	*Target Response*	*Mean*	*S.D.*	*Target Response*	*Mean*	*S.D.*
250	HA1	58.60	62.5	2.22	65.00	68.50	3.40	73.80	76.0	2.70
	HA2		60.40	2.79		66.30	3.16		75.30	2.16
500	HA1	65.40	69.2	1.39	72.60	75.70	3.02	83.90	85.10	3.69
	HA2		66.0	2.16		73.10	2.33		83.50	2.63
1000	HA1	74.90	75.9	3.47	85.00	85.00	2.94	92.20	90.7	2.45
	HA2		74.80	2.82		83.90	2.68		89.90	1.85
1500	HA1	78.50	81.7	4.02	88.30	89.30	3.09	95.20	91.50	1.58
	HA2		80.0	3.71		88.00	2.16		89.10	1.52
2000	HA1	83.00	83.1	3.66	91.70	89.00	2.44	96.30	88.30	1.76
	HA2		82.10	3.17		87.70	1.70		84.80	2.65
3000	HA1	78.70	79.0	3.09	85.70	83.80	3.04	89.50	83.8	2.69
	HA2		77.70	2.75		82.70	1.82		81.20	1.31
4000	HA1	75.70	74.0	2.66	81.30	78.40	1.95	87.20	79.40	3.23
	HA2		73.20	2.85		75.90	2.18		76.80	2.20

As the hearing loss increased, the target values increased, and the target values were highest in the group with severe HL. The visible speech measure showed the similar trend as that of the target curve. The visible speech measure was least in the group with moderate HL and highest in the group with severe HL. This finding is similar to that noted for the traditional REAG.

The investigators in the past have used ±10 dB criteria to determine if the targets are matched by the measured real ear measures (Bryne & Dillon, 1986; Aahz & Moore, 2007). In the present study, the difference between the target and measured visible speech measures was within ±10 dB except at 2 kHz for hearing aid 1 and at 4 kHz for both the hearing aids, in the group with severe HL. Visible speech measures requires more amplification in high frequencies than the traditional real ear aided gain. In groups with moderate and moderately-severe HL, further increase in high frequency gain was possible in both the hearing aids which helped in matching the target curve at high freqeuncies also. In contrary to that, hearing aid gain could not be further increased in group with severe HL to match 2 kHz and 4 kHz targets as the maximum gain limit of the hearing aid in these frequecy regions was reached.

Speech Intelligibility Index

Speech intelligibility index (SII) was tabulated from the visible speech display screen of Fonix 7000 for all the participants. The speech intelligibility index showed variability across different groups in mean and standard deviation (SD), as shown in Table 4. As expected, the SII was maximum in the group with moderate hearing loss (HL) followed by groups with moderately-severe and severe HL, for both the hearing aids.

The SII reflected the amount of acoustic cues available to the participants with hearing loss, in the aided condition. Thus, the speech intelligibility index decreased as the amount of hearing loss increased. The SII is also based on the audibility of the signal presented to the individual with hearing loss (Cox, Alexander & Rivera, 1995). In participants with moderate hearing loss, more acoustic cues were available compared to those with higher degree of hearing loss. Hence, individuals with moderate degree of hearing loss obtained a higher SII compared to the other two groups.

Table 4: Mean and Standard Deviation (SD) of Speech Intelligibility Index with two hearing aids, HA1 & HA2, for three groups of participants.

Measure	*Hearing Aids*	*Groups based on severity of Hearing Loss*					
		Group I		*Group II*		*Group III*	
		Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
SII	HA 1	84.40	1.77	74.60	1.64	65.30	3.30
	HA 2	81.30	2.71	74.10	2.28	64.60	4.76

Speech Identification Scores

Speech identification scores were measured in two different conditions, i.e., when the hearing aid was optimized using REAG for ANSI-digi signal and later when the hearing was optimized using visible speech measurement. Mean and standard deviation (SD) of the aided speech identification scores revealed variations in the aided speech identification scores across the groups and conditions as shown in Table 5.

Table 5: Mean and standard deviation (SD) of the aided speech identification scores (SIS).

Condition	*Hearing Aids*	*Aided SIS (Max = 25)*					
		Group I		*Group II*		*Group III*	
		Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
HA optimized using REAG	HA 1	18.9	1.37	17.8	1.81	14.4	1.89
	HA2	17.8	1.54	17.7	1.63	13.3	1.15
HA optimized using Visible Speech	HA 1	21.0	1.41	19.4	1.89	14.9	1.37
	HA 2	19.8	1.87	19.3	1.56	13.6	1.24

The mean SIS with the hearing aid optimized using visible speech condition was slightly greater than that when the hearing aid was optimized using REAG for ANSI-digi speech signal condition. This suggests that the hearing aid optimized using visible speech yielded a higher SIS than compared to hearing aid optimized using ANSI-digi speech signal. In group III, the difference in SIS was the least when the hearing aid was optimized with REAG using ANSI-digi speech signal and when optimized using visible speech. This reflected the fact that the available gain or audibility was not sufficient to improve the SIS for group with severe HL. This reflected the difference in mean target and visible speech response for the group with severe HL.

The paired t-test was performed to determine the significant difference between the two experimental conditions, i.e., when the hearing aid was optimized using REAG for ANSI-digi signal and later when the hearing was optimized using visible speech measurement. The paired t-test was performed on each group separately. There was a significant difference between SIS obtained when HA was optimized using ANSI-digi speech signal and SIS obtained when HA was optimized using visible speech protocol in the groups with moderate HL and moderately-severe HL ($p<0.001$), with higher SIS obtained when HA was optimized using visible speech protocol.

The speech identification scores obtained when hearing aid was optimized using visible speech, showed an increase in mean scores of SIS in moderate and moderately-severe groups of participants as against hearing aid optimized using ANSI-digi speech signal. The increase in SIS could be attributed to increased audibility in high frequencies when hearing aid is programmed using visible speech. There was no statistically significant increase in SIS for group with severe HL. This finding can be attributed to the inability to further increase hearing aid gain in high frequencies as compared to REAG condition in the Group III. Overall, there was an improvement in speech identification of individuals with hearing loss when hearing aid was optimized using visible speech.

Comparison of different test measures

Correlation between traditional REAG and Visible speech measure

The real ear aided gain for ANSI-digi speech signal obtained separately at each frequency (250 Hz, 500 Hz, 1 kHz, 1.5 kHz, 2 kHz, 3 kHz & 4 kHz) were correlated with that of the visible speech measure. Pearson's correlation was administered between the REAG values and VS values for both the hearing aid conditions. A significant positive correlation was obtained between REAG and visible speech measures when the analysis was carried out on all the 30 participants ($p<0.01$).

Correlation between RMS amplitude of REAG and visible speech measure

RMS amplitude was measured for both the types of real ear measurements, i.e., REAG and visible speech. The mean and standard deviation (SD) of RMS amplitude for REAG and VS are given in Table 6.

Table 6: Mean and Standard deviation (SD) for RMS amplitude for REAG and visible speech measures.

Measure	*Hearing Aids*	*RMS amplitude (dB SPL)*					
		Group 1		*Group 1I*		*Group III*	
		Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
REAG	HA 1	95.98	2.60	106.02	3.19	114.13	2.58
	HA2	94.03	2.78	104.33	3.33	112.52	2.35
Visible Speech	HA 1	93.70	3.61	103.50	1.84	110.80	2.34
	HA 2	93.00	1.82	100.90	2.33	107.1	1.91

The mean RMS amplitude of REAG and Visible Speech varied across the three groups of participants. The RMS amplitude of both the measures was highest in the group with severe HL and least in the group with moderate HL. In other words, as the degree of hearing loss increased, the RMS amplitude of both the REAG and Visible Speech measures increased. This was due to the hearing aids with higher gain and output used for higher degrees of hearing loss.

Pearson's correlation was performed on the RMS amplitude of REAG and RMS amplitude of visible speech. A significant correlation was obtained between RMS average amplitude of REAG and visible speech when the analysis was carried out on all the 30 individuals with hearing loss ($p<0.01$). This suggests that the RMS amplitude of visible speech and REAG measure can be used interchangeably in verification of hearing aid fitting. Further, Pearson's correlation was carried out separately for each of the three groups. Pearson's correlation demonstrated no significant correlation between RMS average amplitude of REAG and visible speech in each of the three groups ($p >0.05$).

Correlation between Speech identification scores, Speech intelligibility index and RMS amplitude of visible speech.

Pearson's correlation was carried out between speech identification scores, speech intelligibility index, RMS amplitude of visible speech for both hearing aids. Following results were found

a. A significant correlation between RMS amplitude of visible speech and speech identification scores was also revealed when the analysis was carried out on all the 30 individuals with hearing loss ($p<0.01$).

b. A significant positive correlation was obtained between speech identification scores and speech intelligibility index when the analysis was carried out on all the 30 individuals with hearing loss ($p<0.01$).

c. A significant correlation between speech intelligibility index and RMS amplitude of visible speech was also obtained when the analysis was carried out on all the 30 individuals with hearing loss ($p<0.01$).

The visible speech measures would be beneficial to verify hearing aids as it would provide both electroacoustic performance of the hearing aid as well as the speech understanding abilities of the individual through SII. Speech intelligibility index which is being displayed on the visible speech screen would provide necessary information about the amount of audible cues present to the hearing aid user. In the present study, visible speech along with speech intelligibility index has been proved to be a efficient verification tool in the hearing aid selection.

Further, traditional real ear measurements have been clinically adopted for the verification of hearing aids (Hawkins & Cook, 2003; Mueller, 2003, Van Vliet, 2003). But, the major disadvantage of traditional real ear measurements (e.g. REAG) is the use of composite noise signals as an input signal to hearing aids (Moore, 2006). These are the signals which are of lowest concern when hearing aid has to perform in real-life situations. The most common signal one is exposed to is the speech stimuli. Hence, verifying hearing aid fitting with composite signal would not give an indication of the performance of a hearing aid in real-life situations.

Visible speech may be the solution to this problem. According to Moore (2006), using visible speech, effective amplification provided by the hearing aid can be assessed using realistic signals such as speech or music and with the aid in its normal mode of operation (with features such as feedback cancellation and noise reduction enabled). Thus, the influence of factors such as number and bandwidth of channels, compression speed, etc., is automatically taken into account. The gains actually achieved for real-life signals such as, speech and music, may differ considerably from the gains measured with steady signals, such as tones and noise (Moore, 2006). The difference depends on the number of channels in the hearing aid, the speed of the compressors, and the compression thresholds. This is the case even when features such as noise reduction or feedback cancellation are not present or are not activated.

To summarize the results, visible speech measure obtained a good correlation with the traditional REAG and SII. Also, there was a positive correlation between SIS and SII. The speech recognition scores improved when hearing aid was optimized using visible speech protocol than compared to traditional real ear measurement protocol. Hence, visible speech along with SII proves to be a better verification tool for the selection of hearing aid.

From the results of the study, it can be inferred that the visible speech measure proves to be a valuable tool for audiologists. It allows markedly improved accuracy in the verification and fitting of hearing aids. It also provides an immediate indication of the audibility of important everyday signal such as speech, including the speech of family members or relatives. Visible speech measure makes it possible to adjust the parameters of hearing aids to optimize the audibility of speech while avoiding loudness discomfort. It involves the client and their relatives in the fitting process, leading to greater understanding and satisfaction, and it is likely to reduce the number of post-fitting visits, saving time and money.

The findings of the present study have important clinical implications. The visible speech protocol is an effective verification tool for the selection of hearing aids. The implementation of visible speech protocol for verification of hearing aid selection withdraws guesswork of an audiologist about the performance of a hearing aid in the real-life situations. The speech intelligibility index provides an indication of speech intelligibility of a hearing aid user. The SII is also displayed on the visible speech measurement screen. Hence, the visible speech along with SII proves to be a valid objective tool for the verification of hearing aid selection.

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