Earmold Venting and its Effects on Different Subjective and Objective Measures

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Abstract

This study aimed to investigate the effect of venting on the different subjective and objective measures in individuals with sloping sensorineural hearing loss. The subjective measures considered for the study included aided warble tone thresholds, uncomfortable loudness levels, speech identification in quiet, speech identification in noise and quality of speech. The objective measure considered was the real ear aided response. The measures were carried out with the digital hearing aid coupled to unvented and vented earmolds. The data were collected from 19 ears of 12 participants with sensorineural hearing loss in two aided conditions i.e., with unvented and vented earmolds. The results revealed that the sound field thresholds obtained in the vented conditions were better compared to that obtained in the unvented condition except at 500 Hz .The UCL values in the vented conditions were slightly higher compared to that obtained in the unvented condition. The speech identification score was slightly higher in the vented condition compared to the unvented condition. The SNR-50 required in the vented condition was lower compared to that required in the unvented condition for 50% identification scores. The quality rating obtained in the vented condition was better than the quality rating obtained in the unvented condition. The REAR was found to be higher for certain frequencies and lower for certain others in the vented condition when compared to the unvented condition. From the present study it can be inferred that the vent when incorporated with the hearing aid-earmold system in the regular clinical hearing aid fitting has many advantages.

Key words: *Vents, aided thresholds, SNR-50, quality, REAR.*

We live in a world of sounds, some of which are meaningful and some of which are just part of our noisy environment. Hearing is the sense that enables sound to be perceived. Any reduction in hearing sensitivity results in hearing loss (Stach, 2003). For the individual with hearing loss it is the response of the hearing aid in ones ear that matters. Different methods are used to find the level of the sound in the individual's ear. One of the methods used is to measure the functional gain, which is obtained by finding out the difference in hearing threshold in a sound field while the person is aided and while he or she is unaided (Dillon, 2001). Other method that can be used is to find the real ear insertion gain which tells us about the amount of gain presented to the eardrum as a result of inserting the hearing aid in the ear (Dillon, 2001).

The level of the sound developed in the ear canal depends on the amount of gain provided by the hearing aid and on the different acoustic modifications that can be incorporated into the earmold. One such modification is a vent. A vent is a second sound path provided in the earmold between the air outside the head or ear and the ear canal (Dillon, 2001). Thus, a vent avoids excessive moisture build-up in the ear canal. The other acoustic modifications that can be incorporated into an earmold include a horn shaped sound bore to enhance the high frequencies and use of dampers in the sound pathway in the earmold or in the ear hook of the hearing aid in order to smoothen the frequency response of the hearing aid.

The quality of the sound perceived through the hearing aid also is an important aspect to be considered while fitting a hearing aid. Sound quality is one of the major complaints of individuals who use hearing aids, specifically the unnaturalness of one's own voice and the disturbance due to other self-generated sounds. Such complaints are due to the blocking of the ear canal by an earmold or hearing aid shell, creating the so-called occlusion effect (Brooks, 1994). The sound being perceived through the hearing aid needs to be as natural as possible. It has been found that acoustic modifications do have an effect on the sound quality perceived and hence on the user satisfaction (Kuk, 1991). Venting is one alternate method of reducing occlusion effect. Other method that can be used include deep canal fitting. This reduces occlusion effect by reducing the vibration of the ear canal wall caused by bone conducted sound (Kiessling, Brenner, Jespersen, Groth, & Jensen, 2005).

Thus, the hearing aid frequency response can be modified by various means either electronically (analog controls or digital controls) or acoustically (venting, damping and horns) in the earmolds (Cox & Alexander, 1983). In the recent digital hearing aids, automatic signal processing circuits are used which modify their amplification depending on the amount of low frequency energy present in the input signal (Agnew, 1996). In the modern non-linear

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multichannel hearing aids the gain can be varied in each frequency band (Kuk, 1996). Thus, the amount of gain in different frequency regions can be manipulated to improve performance. This manipulation can be either through acoustic manipulation or electronic modification. There is a dearth of studies that have evaluated the effect of acoustic modification in the digital hearing aids. With the amount of flexibility that is possible with digital hearing aids, there is a need to see if the acoustic modifications can bring about additional benefit. Hence in the present study, an effort is made to evaluate the effects of vent in the earmold when used with digital hearing aids.

A vent can be described in terms of several important variables. The placement of the vent can be an important variable. With a side-branch or diagonal vent, the connection is made between the outside atmosphere and the canal bore, the angle of which can be varied. When a diagonal vent is used the sound bore and the vent tube should intersect as close to the medial end of the mold as possible (Dillon, 2001). A parallel vent courses the entire length of the canal portion and terminates at the tip of the earmold; never intersecting the sound bore (Hawkins, 1979). A second aspect of the vent that can be varied is its diameter. Practically, it can be varied from less than 1 mm (limited by drill size) to approximately 4 mm (limited by size of ear canal portion). The length of the vent can also be manipulated. With the parallel vent, the length is changed by shortening the canal portion. Changing the angle of the vent alters its length with a diagonal vent (Hawkins, 1979). Creation of a reactance resonance or 'vent associated resonance' is another effect of a vent. Vent associated resonance is a Helmholtz resonance between the acoustic mass of the vent and the compliance of the residual ear canal volume and ear drum. It is reported that the vent associated resonance typically occurs in the 300-750 Hz region (Hawkins, 1979). This increase in low frequency amplification as a result of vent shifts upward in frequency and intensity as the diameter of the vent increases. A vent may also have an effect on the gain of a hearing aid in the high frequencies. Studebaker and Cox (1977) have shown that with a side-branched vent, substantial attenuation above 1000 Hz can occur. A parallel vent does not decrease the high frequencies. Although a side-branch vent attenuates more low frequencies than a parallel vent, it also attenuates the higher frequencies.

A final effect of earmold modifications is their influence on the loudness discomfort level (LDL) and the saturation sound pressure level with an input level of 90 dB SPL (SSPL 90). Hawkins (1979) compared the aided LDLs obtained for pulsed pure tones in persons with hearing impairment with an occluding and non-occluding earmold. The LDLs were much higher for the low frequencies with the non-occluding earmold due to the attenuation provided by this type of earmolds when compared to the occluding earmolds.

The optimization of parameters of the digital hearing aids is usually done with little attention being paid towards the different acoustic modifications of the earmold even though the fitting software provides the recommendations such as vents of different sizes. The studies reviewed here were done before the advent of the modern digital hearing aids. The effect of venting on performance with these hearing aids is less investigated. Hence, the need for the present study was to find out whether venting brings about a significant improvement in the performance when it is incorporated in an earmold that is coupled to a digital hearing aid.

The present study was carried out with the aim of investigating the effects of vented earmold coupled to the digital hearing aids on the subjective and objective measures. The specific objectives were: (1) To investigate the effect of earmold venting on the aided sound field thresholds and the uncomfortable loudness levels. (2) To investigate the effect of earmold venting on the performance of hearing aid as measured on Speech Identification Scores. (3) To investigate whether earmold venting leads to differences in Speech Identifications Scores in noise (4) To investigate whether the earmold venting leads to differences in quality judgment. (5) To evaluate the effects of venting electro-acoustically using real ear aided response.

Method

Participants: The study included 19 ears of 12 participants, the age range of the participants being 48 to 78 years, with a mean age of 66.8 years. All the participants had post-lingually acquired sensorineural hearing loss with an air bone gap less than 10 dB except at 250 Hz. The hearing loss ranged from mild to moderate degree (Clark, 1981), with a pure tone average ranging from 26 dB HL to 55 dB HL (Mean pure tone average of 42.65 dB HL). The participants with sloping configuration of audiogram were considered for the study. The participants had audiograms with a slope of 5-20 dB threshold increase per octave. The speech identification scores of the participants were greater than 75%. All the participants were naive users of hearing aid and had no previous experience in hearing aid use. In addition, all the participants were native speakers of Kannada language and had adequate speech and language.

Instrumentation: The instruments used in the present study included a calibrated dual channel audiometer, Madsen OB-922 (Version 2) with TDH

39 headphones encased in MX-41 ear cushions, B-71 bone vibrator and Martin-Audio loudspeakers with power amplifiers for sound-field testing facility. This audiometer was used to establish warble tone thresholds, speech identification scores and SNR-50. The loudspeakers were located at 0^0Azimuth and 180^0 Azimuth and at a distance of 1 meter from the participant. A personal computer connected to auxiliary input of the audiometer was used for presentation of the recorded speech material. A calibrated immittance meter, GSI-Tympstar (Version 2), was used to rule out middle ear pathology. Another personal computer with HI-PRO and NOAH-3 along with the hearing aid specific softwares was used for programming the digital hearing aids. A calibrated hearing aid analyzer Fonix 7000 was used to perform the real ear measurements.

Programmable digital behind-the-ear hearing aids with a fitting range from mild to moderately severe hearing loss were optimised appropriately for the amount of hearing loss. The hearing aid used in the study had 4 channels, digital noise canceller, feedback phase inverter and up to 4 manually accessible hearing programs.

Custom made hard acrylic shell earmolds were used to couple the digital hearing aid to the test ear of the participant. The earmold was unvented during the initial set of measurements and later a vent was drilled into the same earmold for the second set of measurements. Aided data were collected for both unvented and vented earmold conditions.

Kannada paired words were used for establishing Speech Recognition Threshold (SRT); Phonemically balanced (PB) word lists in Kannada (Yathiraj & Vijayalakshmi, 2005) was used for obtaining the Speech Identification Scores in quiet; Kannada word list (Sahgal, 2005) was used for establishing SNR-50 and a paragraph in Kannada (Sairam, 2002) containing all the speech sounds of Kannada language was used for quality ratings. The quality rating scale developed by Eisenberg and Dirks (1995) was adapted and used in the study. In this scale, six parameters of quality were rated on a ten point rating scale (0-Very poor; 2- Poor; 4- Fair; 6-Good; 8-Very good; 10- Excellent). The six parameters of quality included loudness, clearness, sharpness, fullness, naturalness and the overall impression.

Procedure

The data were collected in three stages.

Stage I - Selection of the participants: The participants were selected based on the selection criteria. For each participant, the air conduction thresholds were established between frequencies 250 Hz to 8000 Hz at octave intervals. The bone conduction thresholds were obtained between frequencies 250 Hz to 4000 Hz at octave intervals. Speech reception threshold (SRT) measurement was initiated at 20 dB SL (*re:* pure tone average) and the level was adjusted till the participant repeated at least two out of the three pairs correctly. Speech identification score (SIS) was measured at 40 dB SL (*re:* SRT). The uncomfortable loudness level for speech was also measured.

Stage II: Programming the hearing aid: Hard shell earmolds were custom made using acrylic material. Parallel venting was made for all the earmolds using the venting diameter recommendations from the hearing aid fitting software. Venting tubes of different diameters were used to maintain constant diameter throughout the vent. The venting was performed on the earmold after the aided data were collected for the earmold without the vent.

The participant was fitted with the digital behind-the-ear hearing aid coupled to custom made earmold, first without a vent and later with a vent incorporated. The test hearing aid was connected to the HI-PRO, which in turn was connected to a personal computer containing the software for programming the hearing aid. The hearing aid was programmed such that it met the target that was based on the audiometric thresholds and NAL-NL1 fitting formula, with acclimatisation level set at 2. The hearing aid parameters were optimised for the participant based on the audibility for the Ling six sounds.

Stage III: Aided testing: The aided testing was carried out in two conditions. First, with the hearing aid coupled to the custom earmold without a vent, then with the hearing aid coupled to a vented earmold. The data on the following measures were collected in each of the two aided conditions.

1. Sound field thresholds
2. Uncomfortable loudness level
3. Speech identification scores (SIS)
4. Signal to noise ratio for 50% identification (SNR-50)
5. Quality rating
6. Real ear aided response

Sound field thresholds for warble tones at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were used to estimate the sound field thresholds. This was done for each test ear of the participant and when the hearing aid was coupled to unvented and the vented earmolds.

Uncomfortable Loudness Level (UCL) for narrow band noise at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were found out. The UCL was measured for hearing aid coupled with the unvented and the vented earmolds. If at any frequency the UCL was not achieved even at the audiometric limits i.e., when it was greater than 92 dB HL, then the maximum limit of the audiometer was considered as UCL for the purpose of calculation.

Speech Identification score (SIS) in quiet were obtained with the participant seated comfortably at a distance of 1 meter and at 0^0 Azimuth, from the loudspeaker of the audiometer. The recorded speech material was presented at 40 dB HL in the sound field, through the auxiliary input of the audiometer. The aided speech identification scores in each of the two aided conditions were measured by presenting separate PB word list, each with 25 words. The total number of words correctly repeated in the list was noted for each of the two aided condition. This was considered as the speech identification score of the participant. This was carried out for each test ear, in each of the two aided conditions and for each of the participant. The SIS was thus tabulated.

Speech identification in noise measurement in sound field condition with the speech material presented at 0^0 Azimuth and the noise were presented through the speaker at 180^0 Azimuth. Both the loudspeakers were located at one meter distance from the participant. The presentation level of the word list was fixed at 40 dB HL and the initial level of speech noise was set at 14 dB below the speech signal and varied systematically to measure the SNR-50. The participant was instructed to repeat the words heard in the presence of noise. The participants were also informed that the level of the noise would change depending on their response. The participants were presented a set of 3 words at each level of noise. If the participant repeated at least 2 out of 3 words of the set, then the level of the noise was increased by 4 dB. If the participant failed to repeat at least 2 words of the set, the level of the noise was reduced in 2 dB steps. At this point, the difference between the intensity of the speech, i.e., 40 dB HL and the competing speech noise in dB HL was considered as the SNR-50. The SNR-50 was tabulated for each test ear of the participant with the hearing aid coupled to the unvented earmold and later to the vented earmold. The process was repeated for each of the participant and the SNR-50 in the two aided conditions. The resultant SNR-50 was tabulated.

The participants were asked to quantify the aided sound quality of the recorded Kannada paragraph (Sairam, 2002) presented at 40 dB HL through the loudspeaker at 0^0 Azimuth and at one meter distance. The quality was rated on a 10 point rating scale. The quality rating was obtained for each test ear of the participant, in the two aided conditions.

Real ear aided response (REAR) were obtained at one foot distance and at 45^0 Azimuth from the loud speaker of the real ear analyzer. To ensure constant insertion depth of the probe tube, a mark was made on the probe tube after placing it adjacent to the earmold such that it extended 5 mm beyond the earmold in the ear canal. Digispeech signal at 65 dB SPL was used as input for the measurement. Initially, the real ear unaided response (REUR) was obtained. Then the real ear aided response (REAR) in each of the two aided conditions was obtained. The REAR measure was obtained for each of the participant with the hearing aid coupled to the unvented earmold and later to the vented earmold. This process was repeated for each test ear of the participant and the REAR was tabulated. Results are given in Table 1.

From the mean values, it can be noted that, the sound field thresholds obtained in the vented conditions were better compared to that obtained in the unvented condition except at 500 Hz. At 500 Hz, the mean threshold is higher in the vented condition. This may be due to the vent which allows low frequencies to escape out of the ear canal (Hawkins, 1979). Hence, a higher sound level is required to reach threshold. The reduction in the sound field threshold seen at 1000 Hz could be due to the increase in the sound level reaching the ear due the vent associated resonance (Hawkins, 1979). However, it must be noted that, these differences were small. Studebaker and Zachman (1970) have reported that a vent with a diameter of 1.5 mm produced a sharp high frequency resonance. In the present study, the reduction in the thresholds at the high frequencies, i.e., at 4000 Hz could be attributed to this high frequency resonance associated with the vent.

To examine if the difference in the mean aided thresholds between the unvented and vented condition was significant, paired t-test was done. The paired t-test showed no significant difference between unvented and vented conditions in the sound field thresholds obtained for all the four frequencies.

Table 1. Mean and standard deviation of sound field thresholds at different frequencies in the two aided conditions, unvented and with vented earmolds

Frequency (Hz)	Aided sound field thresholds (dB HL) (N= 19)			
	Unvented		Vented	
	Mean	SD	Mean	SD
500	16.21	9.64	16.31	9.36
1000	13.58	6.38	12.21	6.89
2000	20.42	9.27	19.68	9.13
4000	23.26	10.73	22.53	12.34

Uncomfortable loudness level (UCL): The mean and standard deviation for uncomfortable loudness level obtained in the two aided conditions for narrow band noise centred at 500, 1000, 2000 and 4000 Hz are shown in the Table 2.

Table 2. Mean and standard deviation of uncomfortable loudness level obtained in the two aided conditions, with unvented and vented earmolds (N= 19)

Frequency (Hz)	Uncomfortable Loudness level (dB HL)			
	Unvented		Vented	
	Mean	SD	Mean	SD
500	83.58	6.48	85.47	5.16
1000	81.15	9.03	82.31	8.65
2000	84.74	6.40	85.37	6.96
4000	86.63	5.38	87.05	5.43

If the UCL at any frequency was not achieved even at the maximum audiometric limits i.e., when it was greater than 92 dB HL, then the maximum limit of the audiometer was considered as UCL for the purpose of calculation.

The mean UCL values reveal that the values obtained in the vented conditions were slightly higher at all the frequencies compared to that obtained in the unvented condition. The data indicates that the participants could tolerate a higher intensity of the sound before it became uncomfortably loud, when the hearing aid was coupled with the vented earmold.

The results of the present study are in consonance with that reported by Hawkins (1979). He compared the loudness discomfort levels (LDL) obtained for pulsed pure tones in persons with hearing impairment wearing hearing aids coupled to an occluding and non-occluding earmolds. He found that the LDLs were much higher for the low frequencies with the non-occluding earmold due to the attenuation provided by this type of earmolds when compared to the occluding earmolds Though the mean UCLs in the vented mold condition were higher than in the unvented condition, paired t-test results for the UCL showed that the difference in the aided conditions between the unvented and vented earmolds were not significant for all the four frequencies considered (Table 3).

From the results obtained from the study for the warble tone thresholds and UCLs, it can be inferred that as the thresholds for the pure tone are lowered and the UCLs improved, this leads to a larger dynamic range for the hearing aid user, except at low frequencies.

Speech Identification Score (SIS): The mean and standard deviation obtained for speech identification scores in the two aided conditions, with unvented and vented earmolds, are given in the Table 4. It was found that the mean speech identification score was higher in the vented condition and this difference was highly significant.

Table 3. Results of paired t-test obtained for UCLs at different frequencies in the two aided conditions with unvented and vented earmolds

Frequency (Hz)	t value	Significance
500	1.761	0.095
1000	0.896	0.382
2000	0.708	0.488
4000	0.555	0.586

Table 4. Mean and standard deviation of Speech identification scores obtained in the two aided conditions, with unvented and vented earmolds (N= 19)

Speech Identification Scores			
Unvented		Vented	
Mean	Standard deviation	Mean	Standard deviation
19.84	2.50	21.53	2.14

Maximum score: 25

Paired t-test showed a significant difference between the speech identification score obtained in the vented and unvented condition [t (18) = 4.4; p< 0.001], with the SIS in vented condition being higher than in the unvented condition. This finding conforms to the findings reported by Studebaker, Cox, and Wark (1978). They found that the mean discrimination scores in quiet with the vented condition were higher compared to that with the unvented earmold condition.

The improved speech identification in the vented condition can be attributed to the lesser low frequency amplification associated with the vent. According to Hodgson and Murdock (1970) the lesser low frequency amplification or even the low frequency attenuation should make aided listening more comfortable and prevent masking of the high frequency sounds that is important for discrimination. Harrison (1969) also found that the speech discrimination scores were higher with modified earmolds. Their study included different earmold modifications including venting.

Signal to noise ratio for 50% identification (SNR-50): The mean and standard deviation for SNR-50 are shown in the Table 5. It was found that the SNR required in the vented condition was lower compared to the SNR required in the unvented condition for 50% identification scores. It was found that with the speech level held constant, 50% identification was obtained even when the difference between the levels of speech and noise was lesser when the hearing aid was coupled to the vented earmold. This result implies that better speech identification in presence of noise can be obtained with a vented earmold when compared to an unvented earmold.

Table 5. Mean and standard deviation of SNR-50 obtained in the two aided conditions with unvented and vented earmolds (N= 19)

SNR- 50			
Unvented		Vented	
Mean	Standard deviation	Mean	Standard deviation
16.63	4.57	15.05	4.54

Paired t-test results showed a significant difference between the SNR -50 obtained in the vented and unvented condition [t (18) = 2.535; p<0.05], with vented condition showing better performance. Studebaker et al. (1978) also found that the mean discrimination scores in noise were higher in the vented condition when compared to the standard earmold condition.

Quality rating: The quality of the perceived speech was quantified using a 10 point rating scale across six parameters of quality. The mean and standard deviation of the six measures of quality are given in Table 6. It was found that the mean quality rating obtained in the vented condition was higher than the quality rating obtained in the unvented condition.

Table 6. Mean and standard deviation for quality rating (Scale 1-10) obtained in the two aided conditions with unvented and vented earmolds (N= 19)

Parameters of Quality	Quality of speech			
	Unvented		Vented	
	Mean	Standard Deviation	Mean	Standard Deviation
Loudness	6.68	2.08	7.53	1.64
Clearness	7.53	1.84	8.05	1.71
Naturalnes s	6.84	1.86	7.58	1.83
Fullness	7.68	1.33	8.10	1.29
Sharpness	7.89	1.56	8.26	1.19
Overall impression	7.81	1.21	8.53	1.13

Paired t-test results showed a significant difference in the quality parameters of loudness, clearness, naturalness and overall impression between the unvented and vented aided conditions. No significant difference was found for the parameters of fullness and sharpness (Table 7).

Table 7. Results of paired t-test for quality rating obtained in the unvented and vented aided conditions

Quality Parameters	t value	Significance
Loudness	2.731	0.014*
Clearness	2.535	0.021*
Naturalness	2.926	0.009**
Fullness	1.569	0.134
Sharpness	1.197	0.247
Overall impression	4.466	0.000**

Note:- *: p<0.05; **: p<0.01

Real Ear Aided Response (REAR): Real ear aided responses were obtained for frequencies from 200 to 6 kHz. The mean and standard deviation of the response measured in the real ear are shown in Table 8.

Table 8. Mean and standard deviation for the real ear aided response in the two aided conditions, unvented and vented earmolds (N= 19)

Frequency (Hz)	Real ear aided response (dB SPL)			
	Unvented		Vented	
	Mean	SD	Mean	SD
200	57.88	3.38	58.04	6.76
300	60.98	4.02	61.00	6.49
400	65.70	7.11	65.43	8.61
500	70.07	8.67	69.47	10.69
600	73.79	9.65	73.65	11.57
700	77.36	9.15	77.24	11.48
800	78.66	9.08	78.68	10.90
900	78.07	9.51	78.10	10.77
1000	76.70	9.77	76.76	10.55
1100	74.88	9.52	74.88	10.04
1200	73.98	9.19	73.76	9.57
1300	75.01	9.01	74.69	9.31
1400	75.93	8.67	75.37	9.10
1500	76.96	7.95	76.70	8.65
1600	78.27	8.47	77.70	8.71
1700	80.06	8.86	79.60	9.34
1800	80.90	9.24	80.54	9.67
1900	79.20	8.82	79.08	9.34
2000	77.86	8.97	77.73	9.45
2500	74.68	8.32	74.95	8.27
3000	79.95	7.61	80.14	7.02
3500	75.49	8.96	76.39	7.54
4000	73.26	9.85	73.81	9.67
4500	66.11	11.34	66.44	12.54
5000	61.31	11.42	63.52	9.52
5500	63.45	10.79	64.24	8.64
6000	59.10	12.16	60.37	10.25
RMS	91.12	8.32	91.43	8.49

It was observed that the sound level reaching the ear in the vented condition was lower in the frequency range of 400 to 700 Hz, 1200 to 2000 Hz. There was an increase in the level of the signal reaching the ear in the vented condition for frequencies of 800 to 1100 Hz which can be attributed to the vent associated resonance. It was also observed that there was an increase in the signal level in the ear canal for frequencies from 2500 to 6000 Hz which could be attributed to the high frequency resonance associated with the vent. The RMS value obtained in the vented condition was higher compared to that obtained in the unvented condition. Paired t-test results showed no significant difference in the real ear aided response between the unvented and vented conditions.

Conclusions

From the present study it can be inferred that the vent when incorporated with the hearing aid-earmold system in the regular clinical hearing aid fitting has many advantages. The thresholds improve and the UCLs are comparatively raised, which in turn leads to a larger dynamic range. In addition, better speech identification is obtained and at lower SNRs. The most important point to be considered is that the perceived quality of the speech in the vented aided condition is rated higher compared to an unvented aided condition. These advantages with the vents were noted for the digital hearing aids that were optimized. Hence, even with finer adjustments made in the digital hearing aids, inclusion of a vent in an earmold brings about additional benefit. This would in turn have an effect on the user satisfaction and continued usage of the hearing aid.

References

Agnew, J. (1996). Hearing aid adjustments through potentiometers and switch options. In M. Valente (Ed.), *Hearing aids: Standards, options and Limitations* (pp 143-177). New York: Thieme medical publishers Inc.

Brooks, D. N. (1994). Some factors influencing choice of type of hearing aid in the UK: behind-the-ear or in-the- ear. *British Journal of Audiology, 28*, 91–98.

Clark, J. G. (1981). Uses and abuses of hearing loss classification. *Asha, 23*, 493-500.

Cox , R. M., & Alexander, G.C. (1983). Acoustic versus Electronic modifications of hearing aid low frequency output. *Ear and Hearing, 4* (4), 190-196.

Dillon, H. (2001). Hearing aid earmolds, ear shells and coupling systems. In *Hearing aids.* Australia: Boomerang press.

Eisenberg, L. S., & Dirks, D. D. (1995). Reliability and sensitivity of paired comparisons and category rating in children. *Journal of Speech and Hearing Research, 38*, 1157-1167.

Harrison, A. (1969). Clinical Uses of Earmold Modifications in Supplying Amplification to a Presbyacusic Population. *International Journal of Audiology*, 8(4), 509-516.

Hawkins, D. B. (1979). Earmold acoustics and modifications for mild and moderate hearing losses. *Journal of the Academy of Rehabilitative Audiology*, 12, 30-46.

Hodgson, W. R., & Murdock, C. (1970). Effect of the earmold on speech intelligibility in hearing aid use. *Journal of Speech and Hearing Research*, 13, 290-297.

Kiessling, J., Brenner, B., Jespersen, C.T., Groth, J., & Jensen, O.D. (2005). Occlusion effect of earmolds with different venting systems. *Journal of American Academy of Audiology*, 16 (4), 237-249

Kuk, F. K. (1991) Perceptual consequence of vents in hearing aids. *British Journal of Audiology, 25*, 163-169.

Kuk, F. K. (1996). Considerations in modern multichannel nonlinear hearing aids. In Valente M (Ed.), *Hearing aids: Standards, options and Limitations* (pp 178-213). New York: Thieme medical publishers Inc.

Sahgal, A. (2005). A comparative study of proprietary and generic prescriptive procedures for non linear hearing aids. Unpublished dissertation submitted to the University of Mysore, in part fulfilment of Masters Degree in Audiology.

Sairam, V. V. S. (2002). Long Term Average Speech Spectrum in Kannada. Unpublished Independent Project submitted to University of Mysore, in part fulfilment of Masters Degree in Speech and Hearing.

Stach, B. A. (2003). *Comprehensive dictionary of Audiology, Illustrated.* Second edition. New York: Thomas Delmar learning.

Studebaker, G. A., & Cox, R. (1977). Side-branch and parallel vent effects in real ears and in acoustical and electrical models. *Journal of American Audiological Society, 3*, 108-117.

Studebaker, G. A., & Zachman, T.A. (1970). Investigation of the acoustics of earmold vents. *The Journal of the Acoustical Society of America, 47(2)*, 1107-1115.

Studebaker, G.A., Cox, R. M., & Wark, D. J. (1978). Earmold modification effect measured by coupler, threshold and probe techniques. *International Journal of Audiology, 17(2)*, 173-186.

Yathiraj, A., & Vijayalakshmi, C. S. (2005). *Phonemically Balanced word list in Kannada.* Developed in Department of Audiology, AIISH, Mysore.