Evaluation of Performance with Occluded and Open-fit Receiver-In-Canal (RIC) Hearing Aids

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Abstract

The present study was designed to evaluate the performance of open fit and occluded fit RIC hearing aids in individuals having flat and sloping sensorineural hearing loss on various subjective and objective measures in open fit and occluded fit conditions. The subjective measures included sound field thresholds, Uncomfortable loudness level for speech noise, Speech identification scores in quiet, Speech recognition threshold in noise (SNR-50), and Quality judgment of recorded speech and own voice. The objective measure considered was Real Ear Aided Gain (REAG). Results showed that the aided sound field thresholds obtained in occluded fit condition was better than that in open fit condition at majority of the test frequencies There was no significant difference between the open fit and the occluded fit RIC hearing aids in speech identification scores in quiet. However, participants performed better in noise on the speech recognition threshold in noise (SNR-50) task. For the quality ratings, there was a significant difference between two aided conditions - open fit and occluded fit - for 'naturalness', 'fullness', and 'overall impression' for flat hearing loss group. For individuals with sloping hearing loss, open fit condition was shown to be better than occluded fit condition. The improvement of own voice quality and reduction of occlusion effect was the most common factor reported by the individuals in open fit condition than occluded fit condition, especially the sloping hearing loss group. On real ear measurements, there was a significant difference between REAG only for certain frequencies in open-fit and occluded condition in the group with flat configuration.

Key words: *RIC hearing aid, aided thresholds, SNR-50, quality, REAG.*

American Speech Language Hearing association (ASHA, 1998) asserts that amplification should provide audibility and comfort for soft and average input levels, and tolerance for high input levels. The primary goal of current hearing aid fitting strategies is to make the speech signal audible in those regions where the sensitivity is reduced, and in the case of high-frequency hearing loss this means providing high-frequency amplification.

Various methods have been attempted to improve speech understanding for persons with high frequency hearing losses while maintaining acceptable physical appearance and comfort. Completely-in-the-canal (CIC) and in-the-canal (ITC) instruments can offer cosmetic advantages; however, occlusion effects often are present and can be problematic. The occlusion effect has been documented as a consistent problem when it comes to maximizing satisfaction with conventional hearing aid fittings (Dillon, 2001; Kiessling, Margolf-Hackl, & Gellar, 2001). Sweetow and Pirzanski (2003) reported occlusion and ampclusion effects in 28% to 65% of hearing aid wearers. The occlusion effect is the sensation of increased loudness especially in low frequencies that a person experiences to self-generated sounds such as vocalization, chewing, and swallowing. Ampclusion is the combination of low-frequency amplification and the occlusion effect (Painton, 1993). Patient complaints about their own voices sounding boomy, hollow, or muffled are often due to the effect of occluding the ear canal.

Audiological management of high frequency hearing loss poses a challenge for audiologist. For them a multi-channel digital hearing aid would be useful. Since the amount of amplification can be adjusted at different frequencies. The other option for such individuals is the open-fit hearing aids. In this type of hearing aid, the ear canal is partially open so that if sounds travel directly, while the high-frequency sounds are amplified through the hearing aid. There are two options in open fitting i.e., BTE with open fit and RIC with open fit.

There has been a resurgence of interest in open-canal fitting hearing aids for individuals with normal hearing in the lower frequencies and some degree of hearing loss in the higher frequencies. More and more audiologists and clients are choosing open-canal fitting hearing aids as a treatment option for hearing impairment. But "open fitting" is not simply "tube fitting" or the use of a larger vent. The openness of the ear canal (versus the occluded condition) modifies the acoustic condition of the ear and may lower the performance of the hearing aid and result in undesirable artifacts unless compensations are made to minimize them (Kuk, Keenan, Sonne, & Ludvigsen, 2005).

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The RIC (receiver-in-canal) BTE hearing aid is a device in which the receiver is separated from the main body of the hearing instrument and placed in the wearer's ear canal. Placement of receiver in the canal offers some advantages over conventional BTE hearing aid design. Using an external receiver saves space in the main housing of the instrument, so BTE part can be dramatically reduced in size. So the placement of the receiver in the canal increases the distance between microphone and receiver. The physical separation of the microphone and receiver may reduce feedback by minimizing structural feedback pathways within the hearing aid (Ross & Cirmo, 1980). Reports indicate that the maximum available gain before feedback for tube-fit BTE hearing aids ranges from approximately 17 to 23 dB (Kuk, 1994; Hellgren, Lurner, & Arlinger, 1999). So without feedback-cancellation algorithms, the use of open devices would be limited to mild degrees of hearing loss. The placement of the receiver-in-canal reduces the residual volume of the canal, thus naturally increasing the sound pressure level in the canal compared with other standard fittings (Hoen & Fabry, 2007). This allows for outstanding amplification opportunities even when larger vents are used.

The output of RIC hearing aid can be delivered to the ear canal through either an open or closed delivery system. The benefits of open-canal fittings have been reported in literature (Johnson, 2006; Mueller, 2006; Taylor, 2006). Open fitting technology has been developed to address the problem of the occlusion effect often present with conventional hearing aids and caused by partially or completely occluded ear canal. So the main motivation for an open fitting hearing aid is the elimination or minimization of the occlusion effect, improved sound quality (both own voice and others voices) and improved localization ability for individuals with high frequency sensorineural hearing loss. The unoccluded ear canal retains its natural resonance characteristics, enhancing the response in the 2 to 3 kHz region and further enhancing sound quality (Mueller & Ricketts, 2006). Furthermore, fitting ranges for open-fit hearing aids are frequently based on measurements made in a closed coupler, which does not accurately approximate gain in an open ear canal, especially in low frequencies.

There is a dearth of literature on the open-fit hearing aids and even lesser studies have been done with RIC hearing aids. Occlusion effect is one of the most common complaints particularly in clients with normal or near normal low frequency hearing loss and some degree of high frequency hearing loss. Kiessling, Brenner, and Jespersen (2005) reported that acoustic mass is directly related to reported occlusion by hearing aid wearers. Vent mass is essential factor relating to occlusion but it is not possible to optimize vent size without small components, optimal placement and reliable digital shell manufacturing techniques. So open-canal fittings are an effective means of overcoming one of the major barriers to acceptance of amplification due to poor quality of own voice resulting from the hearing aid occlusion effect (MacKenzie, 2006).

The clinical application of real-ear measurement is used to verify the appropriateness of a hearing aid fitting and considered a standard of best practice as detailed by the American Academy of Audiology (Valente, Abrams, Benson, Chisolm, & Citron, 2006). Unfortunately, majority of audiologists do not perform real-ear measures as part of their routine practice (Strom, 2006; Kirkwood, 2006). Furthermore, some have inaccurately concluded that real-ear verification of a fitting is not possible in open-canal instruments, due to the contribution of the direct signal that bypasses the hearing aid. In fact, real-ear measurement is just as valid in open-canal fitting as in a conventional fitting (Mueller & Ricketts, 2006). Hence, evidence based research is required to validate these benefits of the open-fit and occluded RIC hearing aids.

The present study is designed to evaluate performance of individuals with open-fit and occluded RIC hearing aid. The main objectives of the study included: (1) to compare the speech identification in quiet, with open-fit and occluded RIC hearing aid, (2) to compare the speech perception in noise, with open fit and occluded RIC hearing aid. (3) to measure the effect of open-fit RIC and occluded RIC on the quality of speech and own voice. (4) to evaluate the real ear measure (REM) with open-fit and occluded fit RIC hearing aid.

Method

Participants: The data was collected from 20 ears of 17 participants (14 males & 3 females). These participants were having acquired hearing loss with adequate speech and language. All the participants were native speakers of Kannada language and the age range was between 15 and 50 years. They had no prior experience with amplification devices. The participants had sensorineural hearing loss (SNHL), with an air-bone gap not greater than 10 dB and they had normal middle ear function. The pure tone average was within 70 dB HL. 10 participants had flat audiogram configuration showing relatively little change in hearing loss (within 10 dB rise or fall over the range from 500 to 5000 Hz) and 10 participants had sloping audiogram configuration with a maximum slope not greater than 40 dB within the range 500 to 4000 Hz (Kennedy, Levitt, Neuman, & Weiss, 1998). The speech identification score (SIS) was greater than 80%. The participants had no complaint of any neurological problems. All the participants had completed at least 10th standard.

Instrumentation: A calibrated sound field audiometer Madsen OB-922 (Version-2) was used for the pure tone audiometry, speech audiometry and for evaluating the aided performance. The audiometer was connected to the head phones (TDH 39 with MX41 AR), B- 71 bone vibrator and two loud speakers (located at 0° Azimuth and 180° Azimuth at a distance of 1 meter). A calibrated GSI-Tympstar (Version-2) immittance meter was used to rule out middle ear pathology. Two digital receiver-in-the-canal (RIC) hearing aids of the same model, one with open fit and the other with occluded fit ear tip were used. This hearing aid had 6-band warp sound processing, adaptive directional microphone, dual stabilizer, digital feedback suppressor (DFS) and noise tracker. A personal computer connected with Hi-PRO, specific programming cable, NOAH-3 and the hearing aid specific software were used to program the hearing aid. A calibrated Fonix 7000 hearing aid analyzer was used for the real ear measurement (REM).

The Speech materials and other evaluation tools utilized in the study included the Kannada paired words for establishing Speech Recognition Threshold (SRT), Phonemically balanced (PB) word lists in Kannada (Yathiraj & Vijayalakshmi, 2005) for obtaining the Speech Identification Scores in quiet, Kannada word list (Sahgal, 2005) for establishing SNR-50, a paragraph in Kannada (Sairam, 2002) containing all the speech sounds of Kannada language for quality ratings. The quality rating scale developed by Eisenberg and Dirks (1995) was adapted and used in the study to assess the quality of speech output through the open-fit and occluded fit RIC hearing aid.

Procedure

The study was carried out in three phases.

Phase I: Audiological evaluation for selection of participants and hearing aid fitting: The routine audiological testing including pure tone audiometry, speech audiometry and immittance evaluation were carried out for each test ear of each participant. The pure tone audiometry was done by estimating the air conduction thresholds between 250 Hz to 8 kHz at audiometric frequencies. The bone conduction thresholds were estimated between 250 Hz to 4 kHz. The modified Hughson and Westlake method (Carhart & Jerger, 1959) was used to estimate both air and bone conduction thresholds. Speech audiometry was administered for the participant in which speech reception threshold, speech identification score (SIS) and uncomfortable level (UCL) for speech were measured.

The participant was seated comfortably on a chair and was fitted with the digital RIC hearing aid coupled to the test ear using an ear tip (open / occluded). Initially, the RIC open fit BTE hearing aid was connected to the HI-PRO through the appropriate programming cable. The HI-PRO was in turn connected to a personal computer with NOAH and the hearing aid specific programming softwares installed. The audiometric threshold data of the participant's test ear were plotted in NOAH-3 software. Then the hearing aid was detected by the programming software and programmed based on NAL- NL1 fitting formula (Dillon, 1999). The initial fitting was done using the 'autofit' feature of the hearing aid programming software. The following programming feature settings were kept constant while fitting the hearing aid such as: Expansion- off; Noise tracker- off; Adaptive directionality- omni; Digital feedback suppression (DFS) - on.

After the initial 'autofit', the participant was asked to repeat the Ling's six sounds presented randomly (/a/, / i/, /u/, /s/, /sh/ & /m/). The gain was optimized for audibility of the Ling's six sounds by adjusting the gain in respective bands of the hearing aid till the participant was able to identify the Ling's six sounds. Finally, the fitting status was saved into the hearing aid. The programming cable was disconnected from the hearing aid and the hearing aid was switched 'on'. This process was followed for programming both open-fit and occluded fit RIC hearing aid for each test ear of the participant.

Phase II: Evaluation of unaided and aided performance: After programming the hearing aid, the warble tone threshold, SIS, SNR-50 and quality judgment were established for each test ear of the participant in three test conditions. The three test conditions included unaided and the two aided conditions. The two aided conditions were one with open fit RIC and the other with occluded fit RIC hearing aid. The following data were collected in each of the three conditions for each test ear of each participant: (1) Sound field warble tone thresholds at 500 Hz, 1 kHz, 2 kHz and 4 kHz (2) Uncomfortable level (UCL) for speech noise (3) Speech Identification Scores (SIS) in quiet condition using recorded PB word list in Kannada, at 40 dB HL (4) Signal to Noise Ratio required for the 50 % correct repetition of the Kannada words (SNR-50) (5) Quality rating of speech using recorded Kannada passage.

Sound field thresholds were obtained for warble tones at 500 Hz, 1 kHz, 2 kHz and 4 kHz. The warble tones were presented through the loud speaker of the audiometer located at a distance of 1 meter and 0^0 Azimuth from the participant. The participant was instructed to raise the finger whenever the warble tone was heard. The starting presentation level of the warble tone was 40 dB HL. If the warble tone was heard, the intensity was decreased in 4 dB steps and if the warble tone was inaudible, the intensity was increased in 2 dB steps till the warble tone was audible again. The minimum intensity at which the participant heard the warble tone being presented at least 50% of the time was considered as the threshold. Thus, the warble tone thresholds were obtained for the frequencies 500 Hz, 1 kHz, 2 kHz, and 4 kHz in unaided condition, aided with individually programmed digital open fit RIC hearing aid and aided with occluded fit RIC hearing aid for each test ear of the participants. The order of the testing was varied among different participants to control the order effect.

The UCL was measured for speech noise using an ascending technique. The instruction to the participant in Kannada was "You are going to hear a noise. The loudness of the noise will get louder and louder. If the noise gets so loud that it becomes uncomfortable, you will have to indicate to me by raising your hand". The procedure was started with the noise level much below the presumed UCL of the participant and the level was increased in steps of 2 dB till the initial UCL was reached. Then a - 4dB and +2 dB steps were used till the UCL of the participant was obtained. Thus, the UCL was measured in the unaided and aided conditions (with open-fit and occluded fit RIC hearing aid). Thus, three sets of UCL were obtained for each test ear of the participant.

The SIS was measured using recorded phonemically balanced (PB) word list in Kannada (Yathiraj & Vijayalakshmi, 2005). The participants were seated comfortably on a chair at a distance of 1 meter, and 0^0 Azimuth from the loudspeaker of the audiometer. The recorded word list on the CD was routed through the auxiliary input of the audiometer to the loud speaker, at 40 dB HL. Before the presentation of the stimuli, the level of the presentation was set at 40 dB HL and level adjustment was done for the calibration tone such that the VU-meter deflections averaged at "0''. The presentation level of the stimuli was monitored with the calibration tone. The SIS was measured by presenting one complete PB word-list of 25 words for each of the two aided conditions. The participant was instructed to repeat the words being presented. 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'. The total number of words correctly repeated in the list was noted. This was considered as the SIS of the participant for the particular test condition. This procedure was repeated in each of the two aided test conditions, i.e., with open-fit and occluded fit RIC hearing aid, for each test ear of the participant.

The speech was presented at 40 dB HL and the signal-to-noise ratio (SNR) in dB at which 50% of the key words were understood correctly, is the speech recognition threshold in noise (Kompis, Krebs & Hausler, 2006). The SNR-50 was measured in a sound-field condition using the recorded Kannada word list developed by Sahgal (2005). The speech material was routed through the auxiliary input of the audiometer to the loud speaker of the audiometer located at 1 meter distance from the participant at 0^0 Azimuth. The presentation level of the speech material was constant at 40 dB HL. The speech noise was routed through the loud speaker located at 1 meter distance from the participant at 180^0 Azimuth. The presentation of the stimuli was monitored with the calibration tone. The initial presentation level of the speech noise was kept at 10 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 the competing speech noise. The participant was presented a set of 3 words at each level of noise. If the participant repeated at least 2 words out of 3 words correctly, then the level of noise was increased by 4 dB steps. If the participant failed to repeat at least 2 words, the level of noise was decreased in 2 dB steps. This was continued till the participant repeated at least 2 out of 3 words being presented. The difference between the intensity of speech signal and noise level in dB, at which participant repeated at least 50% of the words correctly was noted. This difference was considered as the SNR-50. The SNR-50 was measured in two aided conditions only, one with open-fit RIC and the other one with occluded fit RIC hearing aid for each test ear of the participant.

5. The quality judgment was evaluated in terms of overall quality and quality of participant's own voice with open-fit and occluded fit RIC hearing aid in aided conditions only.

Quality of recorded paragraph: The participant was asked to rate both the hearing aids in terms of its quality for speech input conditions tested. The recorded Kannada passage (Sairam, 2002) was presented through computer routed through the loud speaker of audiometer at 40 dB HL. The participants were instructed to listen carefully to the recorded paragraph which was presented. After listening to the passage, the participant was instructed to rate the quality of speech based on six parameters using a 10 point rating scale. The instructions were in Kannada and each of the six parameters of the rating scale was explained to the participant. The instructions in Kannada were "You will now hear to a story. Listen to it carefully. At the end of the story, you will have to rate the quality of speech on different parameters on a rating scale". The parameters and the rating scale for evaluating the quality judgment were: Loudness- from 0 to 10, Clearness- from 0 to 10, Sharpness- from 0 to 10, Fullness- from 0 to 10, Naturalness- from 0 to 10, Overall impression- from 0 to 10.

Each parameter was rated on a 10 point rating scale as follows: 0 – Very poor, 2 – Poor, 4 – Fair, 6 – Good, 8 – Very Good, 10 – Excellent.

The participant was asked to rate the odd numbers if they found the quality to be intermediate between two points. The overall quality rating was done for speech while listening through open-fit and occluded fit RIC hearing aids.

Quality of own voice: The participant was asked to judge about their own voice quality first while wearing the open-fit and then wearing the occluded fit RIC hearing aid. The order of occluded and open-fit RIC hearing aid was changed between participants. The participant was given a Kannada passage and asked to read it aloud for 2 to 3 minutes. After reading the passage, the participant was asked to tell how he/she was hearing his/her own voice through open-fit and occluded RIC hearing aid while talking and reading. According to the participant's judgment, the comments were noted down.

Phase III: Real Ear Measurement (REM): The real ear measurements were carried out using a calibrated Fonix-7000 hearing aid analyzer in the test room. The participant was seated comfortably in the test room at 1 foot distance and 45° Azimuth from the loudspeaker of the hearing aid analyzer.

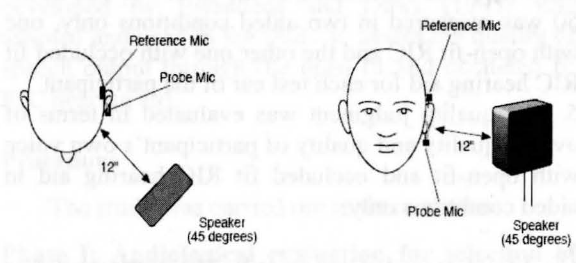

Figure 1. Position of the participant and the loud speaker for real ear measurements.

The hearing aid analyzer was switched 'on'. An otoscopic examination of the test ear was done to make sure that the ear canal was free from wax and any contraindication for REM. The real ear navigation screen of the Fonix-7000 analyzer was accessed. Before, the actual testing started; the levelling of the system was done. The levelling was done by selecting "level" button on the Fonix 7000. It was ensured that the participant's position was not disturbed while levelling. Then, "audiogram" was selected from the navigation screen to enter the audiogram threshold (air conduction) value from 250 Hz to 8 kHz. Later, the "insertion gain" was selected to perform the insertion gain measurement. The target curve was created according to the audiometric threshold data entered at each frequency in the instrument and the "target formula" was selected as 'NAL NL-1' prescriptive procedure. The probe tube was detached from the probe microphone and placed on a flat surface along with the RIC ear tip for marking the probe tube, as shown in Figure 2.

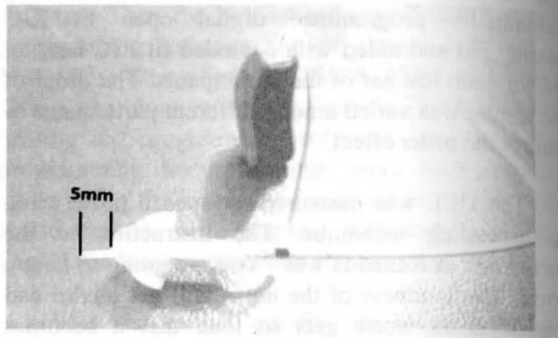

Figure 2. Illustration of the measurement of probe tube length for REUG and REAG.

The ear tip was held next to the probe tube, so that the tube rested along the bottom of the canal part of the ear tip with the tube extending at least 5 mm past from the canal opening. The probe tube was marked by a marker pen where it met the outside surface of the ear tip to ensure proper insertion depth of the probe tube in the canal and near to the tympanic membrane. This length of the probe tube was held constant for unaided and the two aided measurements for each test ear of the participant.

The measurement was done to record real ear unaided gain (REUG), real ear aided gain (REAG) and real ear insertion gain (REIG) with both open-fit as well as occluded fit RIC hearing aids. For the purpose of the study, only REAG was considered.

Measurement of REUG: The probe tube was attached to the probe microphone. Then, the marked probe tube was inserted into the ear canal of the participant's test ear without the ear tip or hearing aid. The reference microphone was located above the ear of the participant. The placement of the reference microphone and probe tube microphone is being shown in Figure 3. The REUR measurement was done using the digi speech signal at 60 dB SPL. The input signal was presented through the loud speaker located at 1 foot and 45° Azimuth from the test ear. The probe tube microphone in the unaided ear canal picked up the input signal and the system measured the sound in the unoccluded ear canal. The level of sound was displayed as gain in dB at different frequencies. The REUG curved was obtained with frequency on X-axis and gain in dB at different frequencies on the Y-axis.

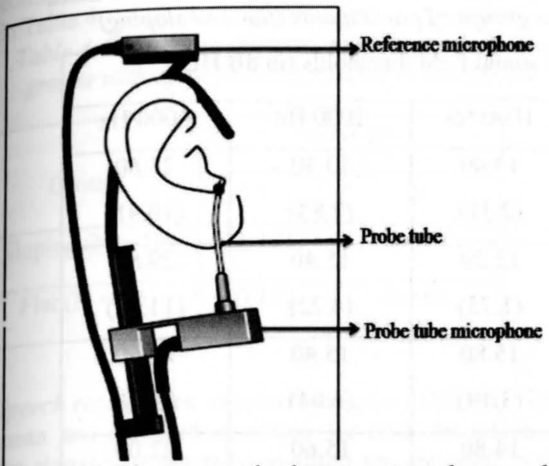

Figure 3. Placement of reference microphone and probe tube microphone for REUG.

Measurement of REAG: The probe tube was placed in the canal, so that the probe tube rested along the bottom of the canal part of the ear tip with the tube extending at least 5 mm past the canal opening. The length of tube inserted was held constant for REUG and REAG measurements. The open fit RIC hearing aid was fitted into the participant's ear while holding the probe tube to make sure the position and length of the probe tube in the canal was not disturbed. Then, the hearing aid which was programmed and optimized for the test ear was switched 'on'. It was ensured that the hearing aid fitting was good and that there was no acoustic feedback. The REAG curve was selected from "curve select" navigation key and the REAG was initiated by pressing the "start" button. When the frequency response was stabilized, the test was stopped by pressing the "stop" button. After removing the open fit RIC hearing aid, the occluded RIC hearing aid was fitted into the participant's ear without disturbing the length of probe tube in the ear canal. The occluded RIC hearing aid was switched 'on'. Then, the REAG curve was selected from 'curve select' in the screen and the test was started by pressing 'start' button. When the aided frequency response curve had stabilized, the test was 'stopped'. The probe tube microphone system measured the dB SPL in the ear canal as delivered by each of the hearing aids. The dB gain at different frequency was displayed as real-ear aided gain (REAG). The order in which the REAG was done with open-fit and occluded fit RIC hearing aid was varied among participants. The real ear aided response (REAG) was displayed for two aided conditions as a curve with frequency versus real ear aided gain (in dB). The values of the two REAG were noted down from the data table at 200 Hz, 500 Hz, 800 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 3500 Hz, 4000 Hz, 4500 Hz, 5000 Hz, 5500 Hz, 6000 Hz, 6500 Hz, 7000 Hz, 7500 Hz and 8000 Hz frequencies for each test ear of each participant, with both the test hearing aids.

Measurement of REIG: The hearing aid analyzer automatically displayed the REIG curve across frequencies. This was automatically calculated by the instrument by subtracting the REUG from the REAG. The REIG was calculated by the instrument by subtracting the REUR from the REAR. The values of the two REIG obtained in open-fit and occluded fit RIC hearing aid were noted down from the data table at 200 Hz, 500 Hz, 800 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 3500 Hz, 4000 Hz, 4500 Hz, 5000 Hz, 5500 Hz, 6000 Hz, 6500 Hz, 7000 Hz, 7500 Hz and 8000 Hz frequencies for each test ear of each participant, with both the test hearing aids. Location of probe tube microphone and reference microphone for unaided and aided REM is shown in Figure 4 and 5.

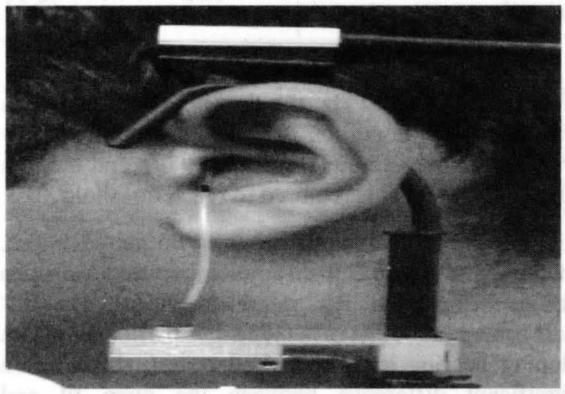

Figure 4. Location of the reference and probe tube microphones for REUG measurement.

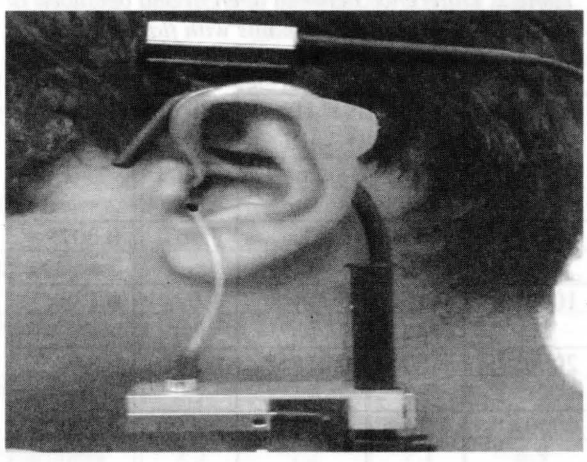

Figure 4. Location of the reference and probe tube microphones for REAG with RIC hearing aid.

Sound field aided warble tone thresholds: The mean and standard deviation of the thresholds (in dB HL) obtained in the two aided conditions at 500, 1000, 2000 and 4000 Hz are shown in the Table 1.

From the mean values, it can be noted that, the sound field thresholds obtained in the occluded fit RIC condition were better compared to that obtained in the open fit RIC condition at most of the test

Table 1. Mean and standard deviation (in brackets) of sound field thresholds obtained in the two aided conditions (with open and occluded fit RIC) for two groups of participants (flat and sloping)

Groups	Aided Condition	Aided sound field thresholds (in dB HL)			
		500 Hz	1000 Hz	2000 Hz	4000 Hz
Flat (N= 10)	Open-fit RIC	13.60 (2.63)	13.40 (2.31)	13.40 (2.83)	28.60 (10.91)
	Occluded fit RIC	11.00 (2.53)	12.20 (1.75)	15.40 (4.22)	29.80 (11.75)
Sloping (N= 10)	Open-fit RIC	26.60 (8.27)	15.80 (3.19)	15.40 (6.04)	22.60 (8.59)
	Occluded fit RIC	23.60 (7.53)	14.80 (3.42)	15.60 (4.19)	22.00 (7.18)

frequencies. At 500 Hz, the thresholds are higher in the open fit condition as the unamplified low frequencies are vented (Hawkins, 1979), and hence a higher sound level is required to reach threshold.

For participants with flat loss, on paired t- test, there was a significant difference between the open fit and occluded fit RIC conditions at 500 Hz ($p < 0.01$) and at 2000 Hz ($p < 0.05$). For participants with sloping hearing loss, on paired t- test, there was a significant difference between the open fit and occluded fit RIC conditions at 500 Hz ($p < 0.01$) only.

Table 2. Difference between open fit and occluded fit RIC conditions for participants with flat and sloping hearing loss

Frequency (Hz)	Flat (N = 10)		Sloping (N = 10)	
	t	p	t	p
500	6.091	0.000*	3.503	0.007*
1000	1.765	0.111	1.627	0.138
2000	3.000	0.015**	0.208	0.840
4000	1.765	0.111	0.669	0.520

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

Uncomfortable level: The uncomfortable level (UCL) for speech noise was measured in both open fit and occluded fit conditions. It must be noted here that the maximum limit of the audiometer for speech noise through loud speaker was 74 dB HL. If the UCL was not achieved even at the maximum audiometric limits, i.e., the UCL was considered as being greater than 74 dB HL. In the participants with flat hearing loss, nine ears had a UCL greater than 74 dB HL in both open fit and occluded fit conditions and one ear had higher UCL in open fit condition than occluded fit condition. Among participants with sloping hearing loss, six ears had higher UCL in open fit condition than occluded fit condition; and four ears showed UCL of >74 dB HL in both conditions. But one from flat and six from the sloping group of the participants showed higher UCL value in open fit condition when compared to the occluded fit condition. In the flat group, the UCLs in 60 % of the participants were higher in the open fit condition than that in the occluded fit condition.

Speech identification Score (SIS) in quiet: The mean and standard deviation obtained for speech identification scores in the two aided conditions with open-fit and occluded fit are given in the Table 3. It was found that the mean speech identification score value was slightly different with occluded fit condition and open fit condition in both groups.

Table 3. Mean and standard deviation (in brackets) of Speech Identification Scores, in the two aided conditions, in flat and sloping groups of participants

Aided condition	Speech Identification Score (SIS) Maximum score = 25	
	Flat (N = 10)	Sloping (N = 10)
Open-fit RIC	22.9 (4.60)	21.60 (3.74)
Occluded fit RIC	22.8 (4.58)	22.2 (2.82)

Paired sample t-test results revealed no significant difference in the speech identification score between the open fit and occluded fit conditions in participants with both flat and sloping configurations of audiogram. The results are shown in Table 4.

Table 4. Significant difference in SIS between two groups with open fit and occluded fit conditions

Groups	SNR-50	
	t	p
Sloping (N = 10)	1.103	0.299
Flat (N = 10)	0.452	0.662

Speech recognition threshold in noise (SNR-50): The mean and standard deviation for SNR-50 which is the signal-to-noise ratio required for obtaining 50% recognition scores are shown in the Table 5. It can be noted that the signal to noise ratio required in the open fit condition was lower compared to than that required in the occluded fit condition for 50% recognition scores. In the sloping group, in both open fit and occluded fit conditions, the mean SNR-50 were more than in the flat group. Lesser SNR-50 values signify that the performance is better even when the difference between the levels of signal (speech) and noise is lesser.

Table 5. Mean and standard deviation (in bracket) of SNR-50 (in dB) obtained in the two aided conditions with open and occluded fit in two groups

Groups	SNR-50	
	Open fit RIC	Occluded fit RIC
Flat (N=10)	15.00 (1.69)	15.40 (3.27)
Sloping (N=10)	18.60 (4.99)	19.60 (4.69)

Ghent, Bray, and Nilsson (2006) reported that RIC with open tip was better than the RIC with occluded tip in the presence of noise. Thus, the reason could be due to reduced effect of noise, which is predominant in the low frequency region which escapes through the vent of the open fit. In another study by Chhabra, Jahfar, and Manjula (2010), the open fit RIC showed better performance than the occluded fit RIC irrespective of anti-mask feature in the test hearing aid being 'on' or 'off' while measuring the performance on SNR-50.

In the present study, though the SNR-50 revealed better performance in noise with the open fit RIC hearing aid. However, the paired sample t-test did not reveal any significant difference between the SNR -50 obtained in the open fit and occluded fit conditions, in both the groups (Table 6).

Table 6. Difference in SNR-50 with open fit and occluded fit RIC conditions between the two groups

Groups	Speech Identification Score (SIS)	
	t	p
Flat (N = 10)	0.429	0.678
Sloping (N = 10)	1.616	0.140

Quality judgements: Quality of recorded paragraph and of own voice were evaluated. The results are given below.

Overall quality for recorded paragraph: Six parameters for the judgement of quality were evaluated as the participants were asked to rate the quality of the recorded paragraph in two aided conditions, i.e., with open-fit and occluded fit RIC hearing aids. Within each condition, these six parameters were rated on a 10 point rating scale. Table 7 depicts the mean and standard deviation ratings for all parameters of quality across the two aided conditions in two groups.

Table 7. Mean and standard deviation (in brackets) for quality rating (0 to 10) in the two aided conditions, open fit and occluded fit RIC, in the two groups

Quality parameters	Flat		Sloping	
	Open-fit RIC	Occluded fit RIC	Open-fit RIC	Occluded fit RIC
Loudness	8.70 (0.94)	8.50 (0.70)	7.3 (1.33)	8.2 (0.42)
Clearness	8.20 (0.63)	7.8 (1.03)	7.6 (1.42)	7.9 (0.73)
Naturalness	8.4 (0.69)	7.3 (0.82	8.3 (0.67)	8.0 (0.94)
Fullness	8.9 (0.73)	7.6 (0.84)	8.5 (0.84)	7.6 (0.84)
Sharpness	7.5 (0.84)	7.2 (1.13)	7.1 (0.73)	6.9 (0.56)
Overall impression	8.4 (0.69)	7.4 (0.69)	7.7 (1.15)	7.9 (0.56)

From Table 7, it can be evident that the mean scores on quality rating in the open fit condition were better than in the occluded fit condition, for flat group. In sloping group, the mean scores of parameters such as 'loudness', 'clearness' and 'overall impression' were better in the occluded fit condition than in the open fit condition. For 'naturalness', 'sharpness' and 'fullness', the mean score was higher in open-fit condition compared to occluded condition.

Paired sample t-test results showed a significant difference between the two aided conditions on the parameters of 'naturalness', 'fullness' and 'overall impression'. No significant difference was found for the parameters of 'loudness', 'sharpness' and 'clearness' between open and occluded conditions, in flat group. For sloping group, there was a significant difference in 'loudness' and no significant difference in the parameters of 'naturalness', 'fullness', 'sharpness', 'clearness' and 'overall impression' between the open fit and the occluded fit RIC conditions.

Table 8. Significant difference between the two aided conditions on six parameters of quality in two groups

Quality parameters	Flat		Sloping	
	t	p	t	p
Loudness	1.000	0.343	2.586	0.029*
Clearness	1.500	0.168	0.818	0.434
Naturalness	3.973	0.003**	0.896	0.394
Fullness	6.091	0.000**	2.212	0.054
Sharpness	1.000	0.343	0.688	0.509
Overall impression	4.743	0.001**	0.557	0.591

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

Quality of own voice: An informal quality rating of his/her own voice in two aided conditions, with open fit and occluded fit RIC hearing aid showed that in the flat group, two participants reported that the open fit was better than the occluded fit; four participants reported that the occluded fit condition was better than the open fit condition; and four participants reported no difference between the open fit and occluded fit RIC hearing aids in terms of quality of his/her own voice.

For the sloping group, seven participants reported that the open fit RIC hearing aid was better than the occluded fit RIC hearing aid; and three participants found both open and occluded fit RIC hearing aids to be the same and that there was no difference between them in terms of quality of own voice. It is noteworthy that none of the participants in the sloping group reported that occluded fit condition was better than the open fit condition. Thus, recommending an open fit RIC for individuals with sloping configuration of hearing loss would be helpful in perception of better quality of others as well as own speech, this might in turn improve the usage of hearing aid in such individuals.

Kiessling, et al. (2005) conducted an investigation of the occlusion effect with open canal and occluded fittings from a single manufacturer. They found no significant difference between the measured occlusion of the occluded eartip. In another study done by Kuk, et al. (2005), there was no occlusion effect below 700 Hz in open canal instrument. MacKenzie (2006) also reported little or no occlusion effect with the open fittings from three different manufacturers. The results of his study indicated highly natural perceptual ratings of own voice sound quality and suggested that open canal fittings are an effective means of overcoming one of the major barriers to the acceptance of amplification which is poor own-voice sound quality resulting from the hearing aid occlusion effect.

Real Ear Aided Gain (REAG): Real Ear Aided Gain (REAG) was obtained for frequencies from 200 to 8000 Hz. The mean and standard deviation of the REAG measured in the real ear are shown in Table 9.

Table 9. Mean and standard deviation (in brackets) for the Real Ear Aided Gain (REAG) at different frequencies, with open fit and occluded fit condition, for the two groups

Frequency (Hz)	REAG in dB for flat hearing loss group (N = 10)		REAG in dB for sloping hearing loss group(N=10)	
	Open fit	Occluded fit	Open fit	Occluded fit
200	47.69 (1.64)	50.70 (2.89)	50.20 (6.79)	52.46 (5.46)
500	48.73 (2.18)	45.71 (5.49)	54.62 (7.95)	57.56 (7.21)
800	52.56 (5.13)	56.27 (5.61)	62.51 (9.83)	70.87 (11.66)
1000	58.12 (7.18)	62.06 (5.40)	68.22 (11.75)	75.17 (12.71)
1500	66.66 (7.28)	67.69 (3.54)	74.09 (11.53)	76.29 (11.28)
2000	73.51 (4.30)	71.24 (3.35)	76.63 (7.82)	77.54 (8.91)
2500	77.21 (2.49)	72.76 (5.15)	79.77 (6.40)	77.71 (10.31)

3000	76.72 (4.21)	72.85 (4.76)	79.87 (4.85)	79.18 (10.41)
3500	73.60 (5.72)	70.56 (6.73)	75.34 (6.81)	73.81 (10.27)
4000	67.71 (8.18)	65.61 (8.94)	68.61 (5.21)	69.50 (9.89)
4500	64.08 (10.13)	62.20 (9.43)	62.74 (6.51)	66.58 (10.23)
5000	60.16 (9.29)	59.67 (8.94)	58.08 (8.17)	61.54 (12.29)
5500	56.06 (11.16)	56.66 (9.71)	55.68 (8.19)	59.27 (11.67)
6000	51.35 (14.54)	50.67 (11.84)	51.85 (7.46)	56.40 (11.91)
6500	43.57 (13.02)	44.38 (13.70)	48.35 (8.90)	52.41 (14.49)
7000	36.32 (9.16)	39.82 (8.64)	44.80 (9.84)	48.75 (16.17)
7500	37.1 (9.17)	38.25 (8.37)	43.17 (10.34)	46.38 (16.01)
8000	37.61 (11.78)	39.00 (13.24)	42.44 (11.23)	44.29 (15.80)

From the mean REAG value, it can be noted that there was a slight difference in real ear aided response between the open fit and occluded fit conditions for all test frequencies. In the lower frequencies, the mean REAG were lesser in the open fit condition than in occluded fit condition, in both the groups. This is because of the escape of low frequencies through the ventilated eartip of the RIC hearing aid.

Paired sample t-test results showed that there was a significant difference between the aided responses at 200 Hz, 800 Hz, 2500 Hz, and 3000 Hz frequencies in the open fit and the occluded fit conditions for the flat group. There was a significant difference in the REAG at 500 Hz, 800 Hz and 1000 Hz between the open fit and the occluded fit conditions, in the sloping group. There was no significant difference between the two aided conditions at other frequencies, in both the groups. The results are shown in Table 10.

Table 10. Difference in REAG between open fit and occluded fit aided conditions for the two groups of participants

Frequency (Hz)	REAG for Flat group (N = 10)		REAG for Sloping group (N = 10)	
	t	p	t	p
200	-3.362	0.008**	-2.021	0.074
500	0.586	0.572	-3.070	0.013*
800	-1.660	0.131	-5.127	0.001**
1000	-1.421	0.189	-4.275	0.002**
1500	-0.503	0.627	-1.454	0.180
2000	1.804	0.105	-0.334	0.746
2500	4.004	0.003**	0.614	0.555
3000	3.108	0.013*	0.337	0.744
3500	2.239	0.052	0.914	0.385
4000	1.233	0.249	-0.424	0.681
4500	1.081	0.308	-1.447	0.182
5000	0.314	0.761	-1.845	0.098
5500	-0.395	0.702	-1.919	0.087
6000	0.447	0.666	-1.749	0.114
6500	-0.215	0.835	-1.297	0.227
7000	-0.935	0.374	-1.098	0.301
7500	-0.401	0.698	-0.956	0.364
8000	-0.342	0.740	-0.641	0.538

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

Conclusions

From the results of the present study, it can be concluded that open fit RIC hearing aid can be an ideal management option for individuals with mild to moderate degrees of sloping sensorineural hearing loss. These hearing aids provide better speech recognition, satisfaction with respect to occlusion, natural and comfort compared to occluded fitting RIC hearing aids. The speech perception in noisy environment would be enhanced when the noise reduction feature of the hearing aid is activated. Open fit RIC hearing aids are beneficial mainly for the high frequency loss due to limited gain at low frequencies.

Acknowledgements

The authors acknowledge with gratitude Dr. Vijayalakshmi Basavaraj, Director, All India Institute of Speech and Hearing, Mysore for permitting to conduct the study at the institute. The authors thank the participants for their co-operation. The authors also thank Ms. Ramya V. for the timely help.

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