Research Article

Does the Receiver Type Used in Receiver-in-Canal Hearing Aids Have an Effect on Real-Ear-to-Coupler Difference and Coupler Response for Flat Insertion Gain Values?

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Short running title: Does the Receiver Type Used in Receiver-in-Canal Hearing…

Highlights:
- The HA1 coupler should be used in real-ear-to-coupler difference (RECD) measurement
- Power receivers in RIC hearing aids have lower RECD compared to standard receivers
- A small frequency difference of 50 Hz can affect the RECD and CORFIG values

ABSTRACT
Background and Aim: Real-Ear-to-Coupler Difference (RECD) is affected by the type of transducer and its coupling method. This study aimed to investigate the effect of receiver type used in Receiver-in-Canal (RIC) hearing aids on RECD and Coupler Response for Flat Insertion Gain (CORFIG) obtained by the same coupling method.
Methods: In this study, the right ears of 30 normal-hearing adults (25 men and 5 women, with a mean age of 28.13±5.62 years) were studied. We used the RIC hearing aids with two standard and power receivers. The foam of the ER-3A insert earphone was used as a coupling system in both receivers. By using the Audiogram Direct test within Phonak's fitting software, 70 dB HL intensity was produced at different frequencies, once in the real-ear and again in the HA-1 coupler. By assessing the difference between real-ear and HA-1 coupler measurements, the RECD was first obtained. Then, the CORFIG was obtained at different frequencies by subtracting the Microphone Location Effect (MLE) and RECD from Real-Ear Unaided Gain (REUG).

Results: The RECD and CORFIG values obtained from the standard receiver at all frequencies were significantly different from those from the power receiver ($p<0.05$), where the use of the power receiver resulted in lower RECD and higher CORFIG. With the increase in frequency, the RECD increased. A small frequency changes of 50 Hz had a significant effect on RECD and CORFIG.
Conclusion: The type of receiver used in RIC hearing aids has a significant effect on the RECD and CORFIG values.
Keywords: Real-ear measurement; real-ear-to-coupler difference; insertion gain; hearing aid

Introduction

With the invention of real-ear measurement devices, the role of the insertion gain method in fitting and prescription of hearing aids became more prominent because audiologists needed less time to measure insertion gain [1]. In the insertion gain method, after placing the probe-tube inside the ear canal, the Real-Ear Unaided Response (REUR) and the Real-Ear Aided Response (REAR) is measured near the eardrum. The difference between aided and unaided responses near the eardrum is called the Real-Ear Insertion Gain (REIG) [2]. This insertion gain measurement method is used for real-ear based verification. The insertion gain can also be obtained from the gain of the 2 cc coupler. Hearing aid manufacturers convert the average gain of the 2 cc coupler into insertion gain to show the insertion gain in their hearing aid software. For this purpose, Coupler Response for Flat Insertion Gain (CORFIG) values are subtracted from the 2 cc coupler gain [3]. This insertion gain measurement method is used for coupler-based verification. Killon and Monser, in 1980, introduced the term CORFIG to convert 2cc coupler gain to REIG. According to them, the CORFIG value is obtained by subtracting the Real-Ear-to-Coupler Difference (RECD) and Microphone Location Effect **(**MLE) from the Real-Ear Unaided Gain (REUG) [4]. For a more accurate estimation of CORFIG value by the hearing aid software, REUG and RECD values of the patient can be entered into the hearing aid fitting software. The hearing aid fitting software uses average MLE values to calculate CORFIG. The CORFIG plays an important role in calculating the insertion gain from the coupler gain, and the RECD value is one of the factors affecting CORFIG [5]. Since some new models of hearing aids can measure RECD [6] and given that RECD is influenced by the type of transducer and its coupling method [7], the question is raised about the effect of the type of hearing aid receiver on RECD and CORFIG. To answer this question, two types of standard and power receivers were used in this study to obtain RECD and CORFIG values. We used a special coupling method in Receiver-in-canal (RIC) hearing aids to measure the RECD and solve the problem of inconsistency between RECDs according to the ANSI/ASA S3.46-2013 standard. In this standard guideline, the same coupling method (foam or earmold) is used for both coupler and real-ear measurements, and only putty should be employed to connect the earmold to the HA1 coupler [8-10]. In this study, foam was used as the coupling method because RECD is used twice in many hearing aid fittings [11]. The first use of RECD in hearing aid fitting is for converting hearing thresholds from audiometry (dB HL) to real-ear thresholds (dB SPL) so that prescription formulas do not use the HL unit in the calculation of hearing aid gain [12]. Prescription formulas, before calculating hearing aid gain, convert Hearing Level (HL) thresholds to Sound Pressure Level (SPL) thresholds near the eardrum as follows:
dB HL threshold+RECD+reference equivalent threshold SPL=real-ear SPL threshold
In the above formula, the RECD values are added to the audiogram thresholds along with the Reference Equivalent Threshold (RET) SPL values. The result is the real-ear SPL thresholds or the SPL near the eardrum, which is the raw material used in the prescription formulas. The second use of RECD in hearing aid fitting is when RECD and MLE are added to the SPL or gain created by the hearing aid in the coupler as follows [9]:
Coupler SPL or gain+RECD+MLE=predicted real-ear SPL or gain
The obtained result is the estimated real-ear SPL or gain. It should be noted that MLE is added to the above equation only for Behind-The-Ear (BTE) hearing aids. Unfortunately, accurate measurement of RECD by BTE hearing aid is a difficult task because when evaluating the real-ear part of RECD, the MLE values should either be removed or be measured correctly, and the effect of the calibration method (substitution method or pressure method) should also be considered [13]. Also, when evaluating the real-ear part of RECD, we should be careful about the acoustic feedback of the hearing aid, because any acoustic feedback can affect the results [7]. For this reason, it is better to use the sound generated by the hearing aid (for audiometric purposes) to obtain RECD values so that, in addition to eliminating the MLE effect, acoustic feedback can be prevented; when audiometry is done with a hearing aid, its microphone is disabled.
Therefore, the same coupling method should be used during hearing threshold evaluation (foam is used in the insert earphones) and hearing aid verification. Otherwise, there will be two different types of RECDs measured with different coupling methods, and this mismatch between RECDs can be problematic. In this study, the foam of ER-3A insert earphone was used as a coupling system in two models of standard and power receivers (Figure

1). This makes it possible to use the same coupling method in verifying hearing aids according to the ANSI/ASA S3.46-2013 standard and eliminate the mismatch problem between RECDs [14]. This article investigates the impact of the receiver type used in RIC hearing aids on RECD and CORFIG by solving the mismatches between RECDs.

Methods

Participants

In this study, the right ears of 30 participants with normal hearing (25 males and 5 females) and a mean age of 28.13±5.62 years (ranged 21–45 years) were studied. All participants had normal middle ear (middle-ear pressure between +50 and –50 daPa, middle-ear compliance value in the range of +0.3 to +1.6 ml with probe-tone frequency of 226 Hz) and their ear canal was free of any cerumen [15]. The study was approved by the ethics committee, and written consent was obtained from all participants. The hearing aid model used in this study was Phonak Vitus+RIC (Phonak, Stäfa, Switzerland). In this hearing aid model, two standard and power receivers were used for RECD measurement in a hearing aid analyzer system (Fonix FP35, Frye Electronics Inc., USA).

Measurements

The hearing aid was placed by putty on the HA1 coupler once with the standard receiver and once with the power receiver, and then the intensity of 70 dB HL at the frequencies of 250, 500, 750, 1000, 1500, 2000, 3000, 4000 and 6000 Hz was produced by the hearing aid and the SPL values were recorded by the microphone in the coupler. For this purpose, Audiogram Direct within Phonak Target fitting software was used. Then, the Coupler-to-Dial Difference (CDD) value was obtained in Excel 2016 software as follows: CDD=Coupler SPL–HL. The CDD is the same as RET SPL; therefore, if the device is calibrated according to the ANSI/ASA 2010 standard, RET SPL values can be used instead of CDD.

To obtain the REUG values, the participants were placed at a distance of 30 cm from the speaker, put at a level similar to the person's ear level at an azimuth angle of 45 degrees. After otoscopy tests, silicone probe tubes were marked with a size of 30 mm for men and 28 mm for women and then placed in their ear canal such that the marked area on the probe tube was at the intertragal notch. We used the 6000-Hz notch method to ensure proper placement of the probe tube [16]. If a 6000-Hz notch is observed in the REUG curve, the probe tube is inserted further into the ear canal such that the 6000-Hz frequency notch disappears and negative REUG values do not occur up to a frequency of 8000 Hz. After speaker calibration by the reference microphone, REUG values were obtained. Then, without moving the probe tube, the hearing aid with a standard receiver connected to the foam was placed in the ear canal, and an intensity of 70 dB HL was produced by the hearing aid at the frequencies of 250, 500, 750, 1000, 1500, 2000, 3000, 4000 and 6000 Hz. The real-ear SPL was recorded by the probe tube connected to the measurement microphone. The same process was done using the power receiver. The RECD value was calculated in Excel 2016 software as follows: RECD=real ear SPL-HL-CDD. After obtaining RECD values for power and standard receivers, the CORFIG value was obtained from both receivers. Since the sound was produced by hearing aids in this study (to measure RECD), it was necessary to use the average MLE values for BTE hearing aids to calculate the CORFIG values [17]. In addition to octave and half-octave frequencies to obtain coupler and real-ear responses, 200 and 700 Hz frequencies were included in the study. For both standard and power receivers, the comparisons were made between 200- and 250-Hz frequencies and between 700- and 750-Hz frequencies.

Statistical analysis

The Shapiro-Wilk test was used to examine the normality of the data distribution, whose results showed that the RECD and CORFIG values in all frequencies had a normal distribution. Therefore, paired t-test was used to compare RECD and CORFIG values of standard and power receivers and also to compare the results of the 200-Hz frequency with the 250-Hz frequency and the results of the 700-Hz frequency with the 750-Hz frequency for both standard and power receivers. Data analysis was done in SPSS v.17 software. $p \leq 0.05$ was considered statistically significant.

Results

By measuring REUG values, the mean resonance frequency near the eardrum was 2566.66 Hz (ranged 2100–3400 Hz) with a mean amplitude of 16.78 dB (ranged 10.30–20.40 dB). Based on the results of paired t-test, there was a significant difference in the RECDs between standard and power receivers at 200 Hz ($p=0.001$), 250 Hz (p=0.001), 500 Hz (p<0.001), 700 Hz (p<0.001), 750 Hz (p<0.001), 1000 Hz (p<0.001), 1500 Hz (p<0.001), 2000 Hz (p<0.001), 3000 Hz (p<0.001), 4000 Hz (p=0.003) and 6000 Hz (p=0.046). The paired t-test results also showed a significant difference in the CORFIGs between standard and power receivers (p<0.05). Due to the use of the same mean MLE and REUG values in the CORFIG measurement of both receivers, it was expected that the CORFIG values, like the RECD value, would be significantly different between the two receivers.

RECD values for two receivers (standard and power) are shown in Figure 2. Positive values indicate that the real-ear SPL was greater than the SPL measured in the HA1 coupler, while the negative RECD values indicate that the real-ear SPL was lower than the SPL measured in the HA1 coupler. Although the RECD graphs for the two receivers were similar, the mean values were significantly different (p<0.05). As you can see in Figure 2, with the increase in frequency, the mean values of RECD increased in both receivers.

The mean values of CORFIG for the two standard and power receivers are shown in Figure 3. Although the CORFIG graphs for these receivers were similar, the mean values were significantly different (p<0.05). The positive values of CORFIG at low frequencies were due to the low values of RECD and MLE. Also, the negative values of CORFIG in the frequencies between 2000 and 4000 Hz were due to the resonance of the ear canal (REUG). The mean values of REUG are shown in Figure 4.

The results of paired t-test for the comparisons between 200- and 250-Hz frequencies and between 700- and 750-Hz frequencies at both standard and power receivers, showed that the frequency effect was significant on the RECD and CORFIG values in both receivers (p<0.001). In Figures 2 and 3, we can see the effect of the frequency on the RECD and CORFIG values by the variations found in each plot line. Table 1 presents the mean and standard deviation of the CORFIG value and its components.

Discussion

According to Jorgensen et al. [12], the factors affecting RECD include the type of transducers, the type of coupling system, and the amount of leakage around the earmold or foam. In this study, by using the foam of ER-3A insert earphone in the receiver of RIC hearing aids and using the HA1 coupler to measure RECD, the type of coupling system and the amount of leakage around foam were controlled. Therefore, any variation in RECD values can be attributed to the type of receiver used in RIC hearing aids. In our study, the mean RECD measured with a standard receiver was significantly different from the mean RECD measured with a power receiver, such that the RECD value obtained from the standard receiver was higher than that from the power receiver. This difference can be due to the impedance difference between the two receivers. Since the SPL measured in the coupler and ear canal depends on the impedance of hearing aids' coupling system and the sound source [7, 12]. Acoustic impedance is the measure of opposition of acoustical flow due to the acoustic pressure. The acoustic impedance of a hearing aid and its receiver determine how much power can be transferred from a receiver into ear canal since the impedance of the ear changes with frequency, changing the source from low impedance to high impedance widens the frequency response of the hearing aid [18]. Since the same hearing aid and coupling system were used in this study, the difference in impedance can be due to the type of receiver used in RECD measurement. On the other hand, RECD is one of the effective factors of CORFIG. The CORFIG values obtained using two receivers were significantly different in the present study. Since the power receiver has a higher acoustic impedance than the standard receiver, the mean RECD value in this receiver was lower than in the standard receiver. Therefore, the CORFIG values from the power receiver are expected to be higher than those from the standard receiver.

When presenting the frequencies of 250 and 750 Hz by the hearing aid, the frequency peak was observed at 200 Hz and 700 Hz; therefore, in addition to octave and half-octave frequencies, these two frequencies were also included in the study. By comparing 200- and 250-Hz frequencies and 700- and 750-Hz frequencies in both standard and power receivers, it was found that the frequency difference (even by 50 Hz) can affect the RECD and CORFIG values, because all the variables affecting RECD and CORFIG values were fixed except for frequency. In Lin et al.'s study [19], the RECD value increased by 3.31 dB when the frequency was doubled. In the present study, at the frequencies of 500–4000 Hz, the RECD values increased by 2.6–3.15 dB with when the frequency was doubled. This can be attributed to the different reactions of the middle and outer ears to the frequency change. For higher-frequency sounds, the ear canal and its tympanic membrane act like a rigid wall. At higher frequencies, the volume in front of the receiver (foam) is only limited to the outer ear, while at lower frequencies, the volume in front of the receiver is more such that, in addition to the outer ear, the middle ear and the compliance of the eardrum have a role in determining the equivalent volume. Since the ear canal volume is less than 2 cc even in men, the volume difference between the coupler and the real-ear can increase as the frequency increases. Since the SPL increases with the decrease in volume, the real-ear SPL is expected to be higher at high frequencies than at lower frequencies, and subsequently, the RECD values will increase.

In this study, the mean RECD measured with standard and power receivers differed from the RECD values reported in Munro and Hatton's study [20]. Although in their study, foam of ER-3A insert earphone was used as a coupling system to measure RECD by hearing aid, their RECD measurement method was different from that in our study. In their study, in addition to using the HA2 coupler, RECD was obtained by subtracting the SPL of the 2 cc coupler from the REAR. In this method, we must disable the hearing aid compression system, the noise reduction circuit, and the hearing aid's feedback cancellation system. In some hearing aids, it is not possible to disable the compression system. Moreover, in this method, the volume control of the hearing aid should be placed in a comfortable listening position, which makes the position of the volume control and the test method different from one clinic to another. In this RECD measurement method, the location of the reference microphone can also affect the sound field measurements. Furthermore, contrary to the results of Munro and Hatton [20], the ANSI/ASA S3.46-2013 standard recommends using the HA1 coupler for the RECD measurements [8]. The use of the HA2 coupler instead of the HA1 coupler in RECD measurement increases the differences in the mean RECD values [7]. In our study, the RIC hearing aids were used, while Munro and Hatton used the BTE hearing aids with an earhook to measure the RECD. The different types of hearing aids can also be one of the reasons for the difference in the mean RECD values. In Munro and Hatton's study [20], although the foam of ER-3A insert earphone connected to the hearing aid was used to measure RECD, we can see a notch in the RECD graph at 2-5 kHz frequencies. This notch can be due to the length of the tube connected to the hearing aid hook, which can be lost if the HA1 coupler is used. However, in our study, since the RIC hearing aid was used, there was no acoustic tube that could cause the formation of a notch at these frequencies. In Munro and Toal's study [7], RECD values were obtained using BTE hearing aids placed in the sound field, and a personal earmold was used to measure RECD. The RECD values obtained in their study were significantly different from the values obtained in our study since the RECD in their study was obtained by subtracting the 2 cc coupler SPL from the REAR, similar to the method used by Munro and Hatton [20]. However, in our study, the HA1 coupler was used in RECD measurement. In Lin et al.'s study [19], the RECD values at different frequencies were higher than those in our study. This discrepancy can be due to the different geometry of the ear canal in different age groups. The changes caused by aging have a significant impact on the geometry of the ear canal [21]. In Lin et al.'s study [19], the RECD was obtained from the age group<16 years, while the RECD in our study was obtained from the age group of 21–45 years. The natural resonance of the ear canal can explain the effect of changes in ear canal geometry on the RECD values. The ear canal is like a tube open at one end and closed at the other. Therefore, the resonant frequency of the ear canal is equal to the velocity of sound in air divided by four times the length of the ear canal. Since RECD is the result of the difference between the values measured in the coupler and the real-ear, due to the fixed geometry of the coupler, the resonance frequency of the ear and RECD changes as the length of the ear canal changes. Contrary to the results of the present study and the study by Munro and Toal [7], Bentler and Pavlovic [22] reported that the RECD values obtained at the frequencies of 200 and 250 Hz were positive. The negative RECD values at low frequencies can be attributed to low-frequency leakage since any acoustic adjustments in the coupling system can have a significant effect on the electroacoustic gain of frequencies below 1000 Hz [22]. If there is lower low-frequency leakage around the earmolds, the CORFIG will have more negative values at low frequencies.

In REUG measurement and CORFIG calculation, it is better to place the loudspeaker at an azimuth angle of 45 degrees. Placing the loudspeaker at a zero-degree azimuth angle causes problems since the natural anti-resonance of the concha causes a deep notch in the 6–8 kHz frequencies of unaided responses. To obtain the insertion gain, REUR values are subtracted from REAR; therefore, we will see an artificial peak in the insertion gain curve [5]. Also, it is very important to pay attention to the appearance of the ear. In this study, it was tried to exclude people with deformities in the concha or ridges in the pinna. In Pahlavan Yali and Maarefvand's study [16], wrestlers with cauliflower ears had significant changes in REUG values (between 2–6 kHz frequencies) compared to those with normal ears. In Killion and Revit's study [23], although the loudspeaker was placed at 45 degrees to obtain the CORFIG values, the obtained values are different from those reported in the present study. The reason for this discrepancy can be related to the difference in the RECD measurement method and the individual REUG values.

One limitation in this study was related to controlling the residual volume of the ear canal after placing one receiver (standard receiver connected to foam) to another receiver (power receiver connected to foam). Other limitation was the impossibility of measuring the acoustic impedance of the sound source. Accurate measurement of the impedance of the hearing aid and the receiver connected to it can be beneficial in interpreting the results.

Conclusion

The use of the ER-3A insert earphone foam in the receiver of receiver-in-canal (RIC) hearing aids makes it possible to use the same coupling method in the verification of hearing aids according to the ANSI/ASA S3.46-2013 standard and eliminates the mismatch between real-ear-to-coupler differences (RECDs). The RECD values obtained with this coupling method showed that the type of receiver used in RIC hearing aids (standard and power receiver) has a significant effect on the RECD and coupler response for flat insertion gain values.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by ethic committee of Shahid Beheshti University of Medical Sciences (Code: IR. SBMU.RETECH. REC.1396. 100).

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Authors' contributions

MB: Study design and acquisition of data, statistical analysis, interpretation of the results, drafting the manuscript; ARN: Study design and supervision, interpretation of the results, and critical revision of the manuscript; HJ: Study design and interpretation of the results, and validation the final revision of the manuscript; AAB: Statistical analysis.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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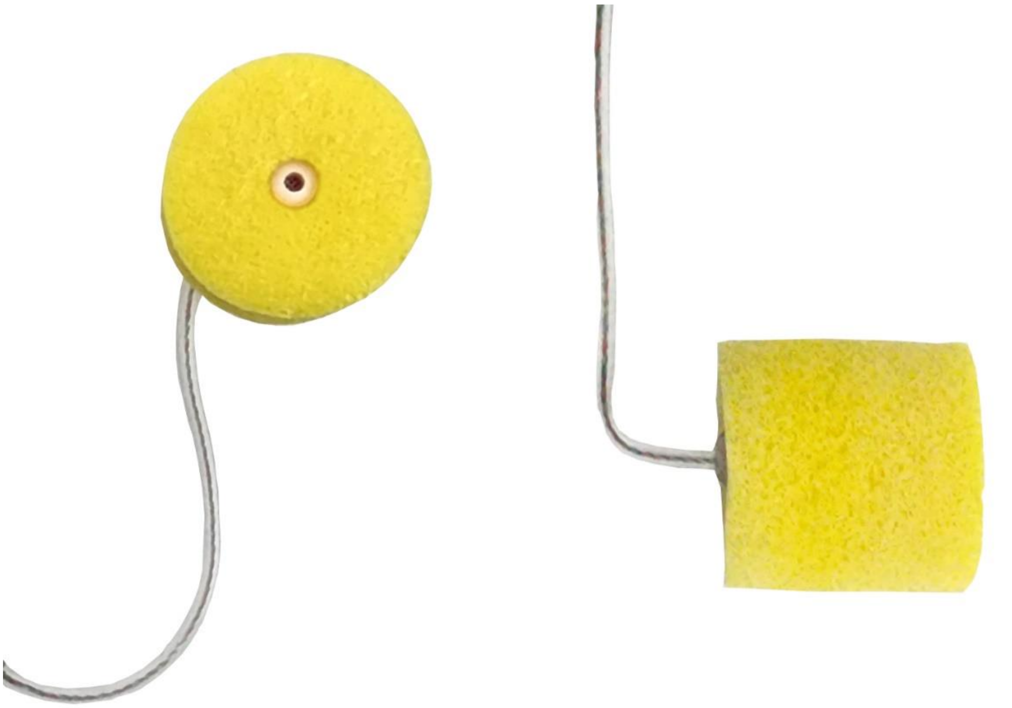

Figure 1. Foam attached to receiver in canal hearing aid receiver

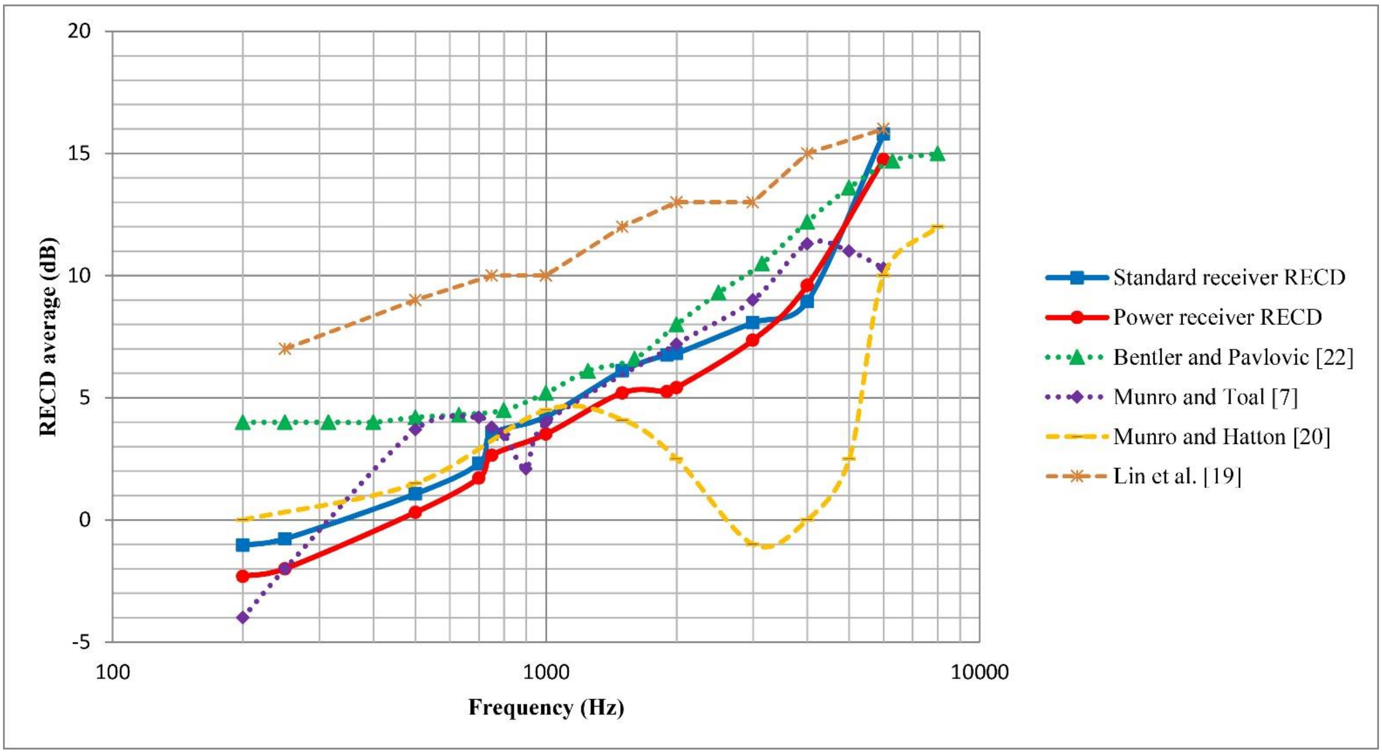

Figure 2. Comparison of mean values of real-ear-to-coupler difference in different studies. RECD; real-ear-to-coupler difference

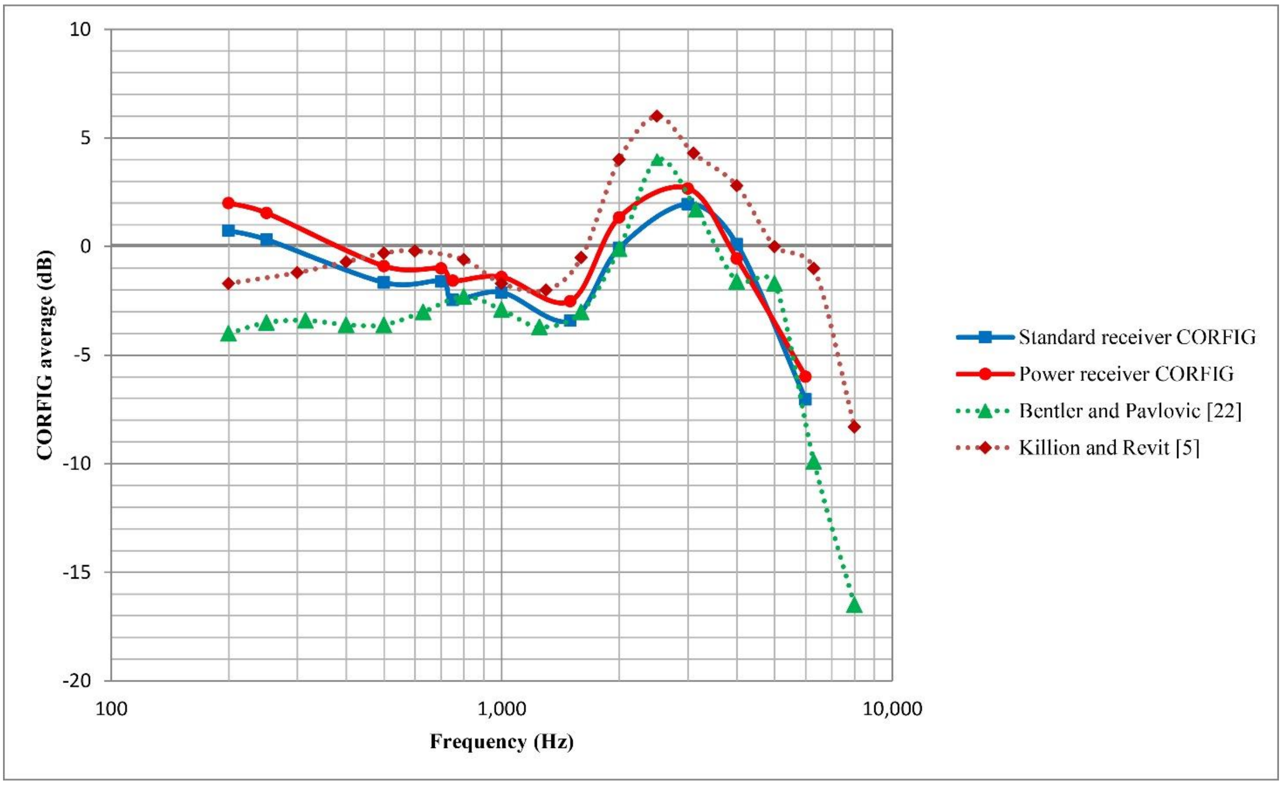

Figure 3. Comparison of mean coupler response for flat insertion gain values in different studies. CORFIG; coupler response for flat insertion gain

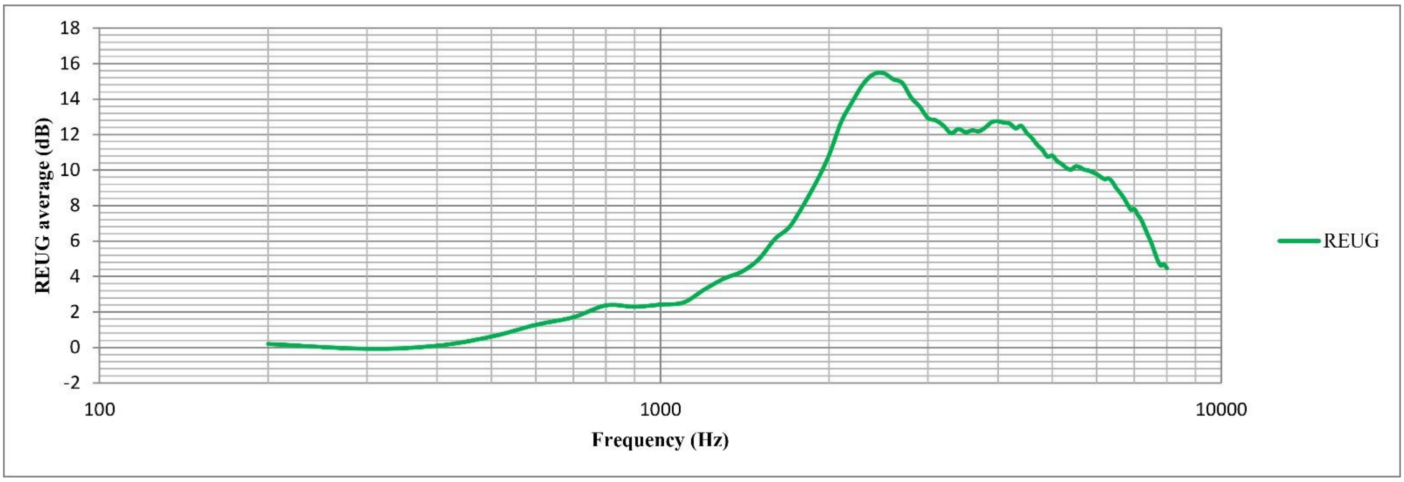

Figure 4. Mean values of real-ear unaided gain as a function of frequency. REUG; real-ear unaided gain

Table 1. The mean and standard deviation of coupler response for flat insertion gain and its components

Frequency (Hz)	REUG (dB)		Standard receiver RECD (dB)		Power receiver RECD (dB)		MLE (dB)	Standard receiver CORFIG (dB)		Power receiver CORFIG (dB)	
	Mean	SD	Mean	SD	Mean	SD	Mean	Mean	SD	Mean	SD
200	0.20	0.45	–1.03	2.32	–2.30	2.41	0.50	0.73	2.26	2.00	2.29
250	0.05	0.44	–0.77	2.22	–1.99	2.36	0.50	0.32	2.22	1.54	2.31
500	0.61	0.68	1.07	1.83	0.31	1.57	1.20	–1.65	1.98	–0.90	1.71
700	1.70	0.81	2.31	1.62	1.71	1.53	1.00	–1.60	1.83	–1.01	1.74
750	2.07	0.81	3.52	1.65	2.64	1.54	1.00	–2.45	1.89	–1.57	1.79
1000	2.41	1.39	4.23	1.79	3.52	1.77	0.30	–2.11	2.57	–1.40	2.47
1500	4.99	2.08	6.10	2.15	5.20	1.97	2.30	–3.41	3.72	–2.51	3.54
2000	10.85	2.07	6.81	2.30	5.41	2.08	4.10	–0.06	3.90	1.34	3.66
3000	12.93	3.08	8.07	2.47	7.36	2.43	2.90	1.96	3.98	2.67	4.13
4000	12.75	3.18	8.94	2.58	9.60	2.65	3.70	0.10	3.84	–0.55	4.32
6000	9.76	3.57	15.80	4.35	14.75	4.33	1.00	–7.03	5.07	–5.99	4.70

REUG; real-ear unaided gain, RECD; real-ear-to-coupler difference, MLE; microphone location effect, CORFIG; coupler response for flat insertion gain